Princeton Instruments
ST-133 Controller

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Chapter 3, First Light provides a step-by-step procedure for placing the system in operation the first time.

Chapter 4, Temperature Control discusses how to establish and maintain temperature control. Also provides information on the effects of long-term vacuum degradation on cooling capability and temperature control.

Chapter 5, Timing Modes discusses the basic Controller timing modes and related topics, including Fast Mode vs. Safe Mode, Free Run, External Sync, Continuous Cleans and Frame Transfer.

Chapter 6, Exposure and Readout discusses Exposure and Readout, together with many peripheral topics, including shuttered and unshuttered exposure, saturation, dark charge, binning and frame-transfer readout.

Appendix A, Specifications includes complete controller and camera specifications.

Appendix B, PTG Module contains a description of the Programmable Timing Generator™ (PTG) together with the PTG specifications and operating instructions.

Appendix C, TTL Control discusses the purpose and operation of the TTL In/Out function.

Appendix D, Cleaning Instructions discusses how to clean the system Controller, Camera and optics.

Appendix E, Outline Drawing contains outline drawings of the ST-133A and ST-133B Controllers.

Appendix F, Plug-In Modules provides a brief overview of the plug-in modules, including directions for their installation and removal.

Appendix G, Interline CCD Cameras describes operating considerations for cameras having an Interline CCD.

Appendix H, MicroMAX DIF Camera describes DIF (Dual Image Feature) camera and its operation.

Appendix I, Installing the Computer-Controller Interface provides detailed directions for installing either the PCI (TAXI®) or USB 2.0 interface in the computer and making connections to the Controller.

Safety Related Symbols
Used in This Manual

Caution! The use of this symbol on equipment indicates that one or more nearby items should not be operated without first consulting the manual. The same symbol appears in the manual adjacent to the text that discusses the hardware item(s) in question.

Caution! Risk of electric shock! The use of this symbol on equipment indicates that one or more nearby items pose an electric shock hazard and should be regarded as potentially dangerous. This same symbol appears in the manual adjacent to the text that discusses the hardware item(s) in question.

Chapter 1

Description

Introduction

Overview: The Model ST-133 is a compact, high performance CCD Camera Controller for operation with Princeton Instruments[*] cameras. Designed for high speed and high performance image acquisition, the controller offers data transfer at speeds up to 1 megapixel per second, standard video output for focusing and alignment and a wide selection of A/D converters to meet a variety of different speed and resolution requirements.

Function: Able to operate with a variety of different cameras and CCD arrays, with support for several popular computer platforms and application software packages, the ST-133 Controller makes it possible to assemble an image acquisition system precisely tailored to your specific needs. In operation, analog data acquired by the camera is routed to the controller where it is converted to digital data by specially designed, low-noise electronics supporting a scientific grade Analog-to-Digital (A/D) converter.

Two complete analog channels, each with its own A/D converter, are available, with switching between the two channels under software control for total experiment automation.[*]

Modular Design: In addition to containing the power supply, the controller contains the analog and digital electronics, scan control and exposure timing hardware, and controller I/O connectors, all mounted on user-accessible plug-in modules. A Programmable Timing Generator™ (PTG) module is also available that allows the controller to be used in conjunction with the PI-MAX® camera in gated experiments without need for an external timing generator. This highly modularized design gives flexibility and allows for convenient servicing.

Flexible Readout: There is provision for extremely flexible readout of the CCD. Readout modes supported include full resolution, simultaneous multiple subimages, and nonuniform binning. Single or multiple software-defined regions of interest can also be tested without having to digitize all the pixels of the array. Completely flexible exposure, set through software, is also fully supported.

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[*] The ST-133 controller must be factory configured for operation with an LN-cooled detector. For this reason, a controller purchased for operation with an LN-cooled detector can only be used with an LN-cooled detector. Similarly, a controller purchased for operation with a TE-cooled detector ***cannot*** be used with an LN-cooled detector.

[*] Depending on the camera with which the ST-133 is intended to operate, a given ST-133 may support one or two A/D converters. The converter(s) must be specified at the time of purchase.

High Speed Data Transfer: Data is transferred directly to the host computer memory via a high-speed interface (TAXI or USB 2.0 protocol) link. A frame buffer with standard composite video, either RS-170 (EIA) or CCIR, whichever was ordered, may also be provided. The digital data at the output of the A/D converter is then transferred at high speeds to the host computer.

For the TAXI protocol, a proprietary PCI card places the data from the controller directly into the host computer RAM using Direct Memory Access (DMA). The DMA transfer process ensures that the data arrives at sufficiently high speed to prevent data loss from the controller. Since the data transfer rate is much higher than the output rate from the A/D, the latter becomes the limiting factor for the data acquisition rate. Once the digital data is in RAM, the image acquisition program can transfer the image into its own working RAM for viewing and further processing.

Applications: With its small size, fully integrated design, support for a variety of cameras, CCD arrays, and computers, temperature control, advanced exposure control timing, and sophisticated readout capabilities, the ST-133 Controller is well suited to both general spectroscopy, macro imaging and microscopy applications.

Chapter 2
Getting Started

Introduction

This chapter will help you get off to a good start with your ST-133 Controller. In addition to descriptions of such basics as unpacking and grounding safety, the chapter includes discussions of the requirements that have to be met before the camera can be switched on. Included are environmental, power, computer, and software requirements. Also provided are descriptions of the front and rear panels of the components, together with discussions of mounting, imaging and other topics. Users are advised to read this chapter in its entirety before powering up the system.

Unpacking

During unpacking, check the controller for possible signs of shipping damage. If there are any, notify Roper Scientific and file a claim with the carrier. If damage is not apparent but controller specifications cannot be achieved, internal damage may have occurred in shipment.

Equipment and Parts Inventory

The complete system consists of a camera, a controller and other components as follows:

- **Camera to Controller cable:** DB25 to DB25 cable. Standard length is 10 ft (6050-0321 for TE-cooled cameras; 6050-0361 for LN-cooled). Also available in 6', 15', 20', and 30' lengths.

- **Controller to Computer Interface (TAXI or USB 2.0):**
  Note: For convenience, in the following operating-procedure discussions, this manual refers to a Pentium™ PC equipped with a PCI high-speed interface card and using WinView/32 software. Nevertheless, the manual does apply as well to operation with other computers and software. Interface components, as follows, could be required.

  - **TAXI interface**

    High Speed PCI Interface board: High-speed serial interface card installed in the host computer.

    TAXI Interface Control Module: Interface module installed in the ST-133.

    Cable: DB9 to DB9 cable. Standard length is 25 ft (6050-0148-CE). Lengths up to 165 ft (50 m) are available.

- **USB 2.0 interface** (Supported by versions 2.5.14 and higher of WinView/32 and WinSpec/32. PTG and USB 2.0 compatibility supported by versions 2.5.15 and higher.)

  USB 2.0 Card: USB 2.0 interface card installed in the host computer.

  USB 2.0 Interface Control Module: Interface module installed in the ST-133.

  Cable: USB cable. Standard length is 16.4 feet (5 meters) (6050-0494). Other lengths may be available. Contact Customer Service for more information

- **PTG to PI-MAX cable:** (6050-0369 or 6050-0406) if PTG is installed. This cable interconnects the **Timing Gen** connector on the PTG module with the **Timing Gen** connector on the PI-MAX.

- **Computer:** Can be purchased from Roper Scientific or provided by user.

- **Other Components:**

  - Intensified cameras would additionally require a high-voltage power supply and/or gate pulser.

    Note: The PI-MAX camera is an exception because its high-voltage pulsing circuits are internal. It would, however, still require a PTG or DG535 Timing Generator.

Grounding and Safety

The apparatus described in this manual is of Class I category as defined in IEC Publication 348 (Safety Requirements for Electronic Measuring Apparatus). It is designed for indoor operation only. Before turning on the controller, the ground prong of the power cord plug must be properly connected to the ground connector of the wall outlet. The wall outlet must have a third prong, or must be properly connected to an adapter that complies with these safety requirements.

WARNING

If the equipment is damaged, the protective grounding could be disconnected. Do *not* use damaged equipment until its safety has been verified by authorized personnel. Disconnecting the protective earth terminal, inside or outside the apparatus, or any tampering with its operation is also prohibited.

Inspect the supplied power cord. If it is not compatible with the power socket, replace the cord with one that has suitable connectors on both ends.

WARNING

Replacement power cords or power plugs must have the same polarity as that of the original ones to avoid hazard due to electrical shock.

Environmental Requirements

- Storage temperature -20°C to 55°C
- Operating environment 0°C to 30°C
- Operating temperature range over which specifications can be met is 18° C to 23° C

- Relative humidity ≤50% noncondensing.

Power Requirements

The ST-133 Controller can operate from any one of four different nominal line voltages: 100, 120, 220, or 240 VAC. Refer to the Fuse/Voltage label on the back of the ST-133 for fuse, voltage, and power consumption information.

The plug on the line cord supplied with the system should be compatible with the line-voltage outlets in common use in the region to which the system is shipped. If the line cord plug is incompatible, a compatible plug should be installed, taking care to maintain the proper polarity to protect the equipment and assure user safety.

The power module contains the voltage selector drum, fuses and the power cord connector. The appropriate voltage setting is set at the factory and can be seen on the back of the power module.

Each setting actually defines a range and you should select the setting that is closest to the actual line voltage. The fuse and power requirements are printed on the panel above the power module. The Power Module contains two fuses. The two fuses are of different values and both change according to the value of the selected line voltage as indicated on the back panel. The correct fuses for the country where the ST-133 is to be shipped are installed at the factory.

If you need to replace a fuse or change the voltage selection, refer to Appendix D, page 80, for instructions.

WARNING

Be sure to use the proper fuse values and types for the controller and camera to be properly protected.

Computer Requirements

Host Computer Type

Note: The following information is only intended to give an approximate indication of the computer requirements. Please contact the factory to determine your specific needs.

TAXI Protocol:

- AT-compatible computer with 200 MHz Pentium® II (or better).
- Windows® 95, Windows® 98SE, Windows® ME, Windows NT®, Windows® 2000, or Windows® XP operating system.
- High speed PCI serial card (or an unused PCI card slot). Computers purchased from Roper Scientific are shipped with the PCI card installed if High speed PCI was ordered.
- Minimum of 32 Mbytes of RAM for CCDs up to 1.4 million pixels. Collecting multiple spectra at full frame or high speed may require 128 Mbytes or more of RAM.
- CD-ROM drive.
- Hard disk with a minimum of 80 Mbytes available. A complete installation of the program files takes about 17 Mbytes and the remainder is required for data

storage, depending on the number and size of spectra collected. Disk level compression programs are not recommended.

- Super VGA monitor and graphics card supporting at least 256 colors with at least 1 Mbyte of memory. Memory requirement is dependent on desired display resolution.
- Two-button Microsoft compatible serial mouse or Logitech three-button serial/bus mouse.

USB 2.0 Protocol:

- AT-compatible computer with Pentium 3 or better processor and runs at 1 GHz or better.
- Windows 2000 (with Service Pack 3), Windows XP (with Service Pack 1) or later operating system.
- Native USB 2.0 support on the motherboard or USB Interface Card (Orange Micro 70USB90011 USB2.0 PCI is recommended for desktop computers and the SIIG, Inc. USB 2.0 PC Card, Model US2246 is recommended for laptop computers).
- Minimum of 256 Mb of RAM.
- CD-ROM drive.
- Hard disk with a minimum of 80 Mbytes available. A complete installation of the program files takes about 17 Mbytes and the remainder is required for data storage, depending on the number and size of spectra collected. Disk level compression programs are not recommended.
- Super VGA monitor and graphics card supporting at least 256 colors with at least 1 Mbyte of memory. Memory requirement is dependent on desired display resolution.
- Two-button Microsoft compatible serial mouse or Logitech three-button serial/bus mouse.

Controller Features

Front Panel

POWER Switch and Indicator: The power switch location and characteristics depend on the version of ST-133 Controller that was shipped with your system. In some versions, the power switch is located on the on the front panel and has an integral indicator LED that lights whenever the ST-133 is powered. In other versions, the power switch is located on the back of the ST-133 and does not include an indicator LED. Figure 1 shows the two locations
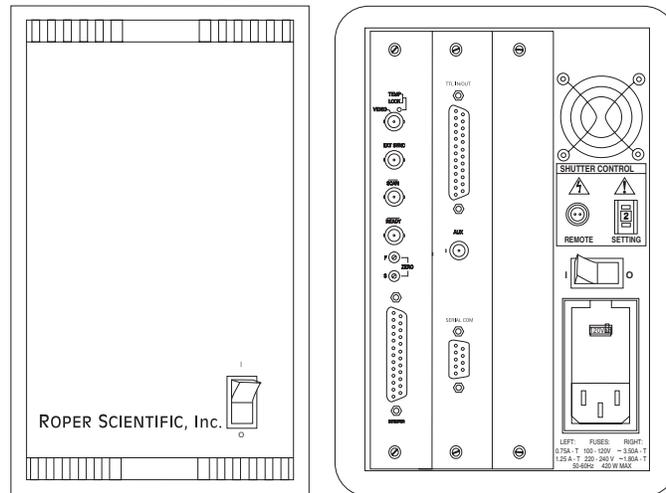
Figure 1. Power Switch Location
(ST-133A and ST-133B)

Back Panel

Fan: There is an internal fan located at the back panel behind the exhaust grill. Its purpose is simply to cool the controller electronics. This fan runs continuously whenever the controller is powered. Air enters the unit through ventilation slots on the sides and bottom, flows past the warm electronic components as it rises, and is drawn out the rear of the controller by the fan. It is important that there be an adequate airflow for proper functioning. As long as both the controller's intake ventilation slots and the fan aren't obstructed, the controller will remain quite cool.

Shutter Control:[*] Directly below the fan are the Shutter Power connector and the Shutter Setting dial. The Shutter Power connector can be used to drive an external shutter if the camera isn't equipped with an internal shutter.

WARNING!

> If the camera is equipped with an internal shutter, then the Shutter Power connector should not be used to drive an external (second) shutter. This configuration will result in under-powering both shutters and may cause damage to the system. *In a system that requires both an internal and an external shutter, use the TTL* **SHUTTER** *signal, provided as the default output at the* $\overline{\text{SCAN}}$ *connector, to control the external shutter.*

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[*] If an ST-133 is shipped with a camera having an Interline CCD chip, the Shutter Control **Remote** connector and **Setting** dial may not be supplied. If this is the case, the corresponding panel openings will be plugged.

Suitable driver electronics will also be required. See the **Note** *on page 20 for information on how the signal provided at the* $\overline{\text{SCAN}}$ *connector is selected.*

REMOTE: The shutter-drive pulses are provided at the **Remote** connector.

WARNING: Dangerous live potentials are present at the **Remote** Shutter Power connector. To avoid shock hazard, the Controller power should be OFF when connecting or disconnecting a remote shutter.

SETTING: The Shutter Setting selector sets the shutter hold voltage. Each shutter type, whether internal or external, requires a different setting. Consult the table below to determine the proper setting for your shutter. *The Shutter Setting dial is correctly set at the factory for the camera's internal shutter if one is present.*
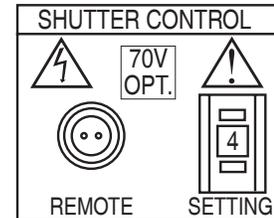
Figure 2. ST-133 Rear Panel with 70 V Shutter Option

Note: With a PI-MAX camera, the setting doesn't matter, unless the system includes an external shutter (typically a slit shutter for spectroscopy) to be powered from the ST-133. If this is the case, the correct setting would be "1".

Shutter Setting*	Shutter Type
1	25 mm Roper Scientific supplied External shutter (typically an Entrance slit shutter)
2	25 mm Roper Scientific Internal shutter
4	35 mm Roper Scientific Internal shutter (requires 70 V Shutter option)
5	40 mm Roper Scientific Internal shutter (supplied with LN camera having a 1340×1300 or larger CCD)
* Shutter settings 0, 3, and 6-9 are unused and are reserved for future use.	

Table 1. Shutter Setting Selection

WARNING

An incorrect setting may cause the shutter to malfunction or be damaged. Cameras having a 35 mm shutter, such as an NTE having the 1340×1300 CCD, must be used with an ST-133 having the 70 V shutter option installed (indicated on the back panel as shown in Figure 2). An ST-133 having this option cannot be used with a camera having the small (standard) shutter, even by selecting a lower number, because the shutter could be permanently damaged by the high drive voltage and larger stored energy required to drive the 70 V shutter.

Power Input Module: This assembly, located at the lower right of the controller back panel, has three functions:

- Connecting the AC power;

- Selecting the line voltage, and

- Protective Fusing.

Controller Modules: There are three controller board slots. Two are occupied by the plug-in cards that provide various controller functions in all ST-133s. The **Programmable Timing Generator**, if present, is installed in the third slot. Otherwise the third slot is covered by a blank panel. The left-most plug-in card is the **Analog Control** module. Adjacent to it is the **Interface Control** module. The modules align with top and bottom tracks and mate with a passive backplane. For proper operation, the location of the modules should not be changed. Each board is secured by two screws that additionally serve to ground each module's front panel. A detailed discussion of how to remove and insert modules is provided in Appendix F, which begins on page 83.

WARNING

To minimize the risk of equipment damage, a module should *never* be removed or installed when the system is powered.

WARNING

If you should remove a module, take care not to overtighten the screws when you reinstall it. They should be tightened with a screwdriver to where they are snug *and no further*. Excessive tightening could damage the internal brackets.

Analog/Control Module: This module, which should always be located in the left-most slot, provides the following functions:

- Pixel A/D conversion,

- CCD scan control,

- Timing and synchronization of readouts,

- Video output control, and

- Temperature control.

In addition to the 25-pin connector provided for the camera cable, there are four BNC connectors and an LED, as discussed in the following paragraphs.

TEMP LOCK LED: This lights to indicate that the temperature control loop has locked and that the temperature of the CCD array will be stable to within $\pm 0.05°C$. The actual lower temperature limit that can be achieved will depend on a number of factors, including the laboratory temperature, and on whether the optional fan accessory has been installed.

Note: There is provision in the hardware for reading out the array temperature at the computer. This temperature feedback display is very convenient for monitoring the temperature control status as it progresses towards temperature lock. To determine when lock occurs, however, use the Temperature Lock indication (LED or **locked** message displayed in the WinView/32 Setup/Detector Temperature dialog box). Note that it may take another 20 minutes after lock is reported before maximum stability is achieved.

VIDEO / AUX BNC connector: Depending on the system, this connector may be labeled **Video** or **Aux**.

Aux: Not currently activated. Reserved for future use.

Video: The composite video output is provided at this connector. The amplitude is 1 V pk-pk and the source impedance is 75 Ω. Either RS-170 (EIA) or CCIR standard video can be provided and must be specified when the system is ordered. The video should be connected to the monitor via 75 Ω coaxial cable and it must be terminated into 75 Ω. Many monitors have a switch to select either terminated or unterminated operation.

Note: If more than one device is connected to the video output, the *last* device is the one that should to be terminated in 75 Ω. For example, to connect the video output to a VCR as well as to a monitor, the cable from the controller video output should be connected to the video input connector of the VCR, and another 75 Ω cable should extend from the video output connector of the VCR to the 75Ω input of the monitor. Do *not* use a BNC TEE to connect the controller video output to multiple devices.

One of the limitations of scientific non-video rate cameras has been their difficulty in focusing and locating fields of view. The ST-133 solves this problem by its combination of high-speed operation with the implementation of true video output. This makes focusing and field location as simple as with a video camera. This video output also makes possible archiving an experiment on a VCR, producing hardcopy data on a video printer, or even implementing autofocusing stages.

The video output must be selected by the Application software. In the case of WinView/32, this is done by selecting **Video** from the Acquisition menu. There is also provision in WinView/32 for intensity-scaling the video output, that is, selecting the specific gray levels to be displayed on the 8 bit video output.

In addition to intensity-scaling, you also need to be concerned about how the array pixels map to the video display. The 756×486 resolution of a typical video monitor corresponds well with the array size of a Kodak KAF-0400 (768 x 512) or EEV CCD-37 (512 x 512).

In the case of an EEV CCD47-10 (1024×1024), the number of array pixels far exceeds the number of monitor pixels and mapping must be considered more carefully. WinView/32 software's **Video Focus** mode (accessed from the Acquisition Menu) provides a Pan function that allows any one of nine different subsets of the array image to be selected

for viewing on the video monitor with only a single-frame delay. An associated zoom function provides 1x, 2x, or 4x viewing. At 1x, the entire array image is displayed, but at reduced resolution (pixels are discarded and fine detail could be lost). At 2x, the mapping is 1:1 and the image portion selected by the Pan function is provided. The regions overlap, allowing the entire array image to be examined with no loss of resolution. At 4x, array pixels are enlarged so that a smaller part of the array image is displayed as selected by the Pan function.

Once proper focus has been achieved, the user can transfer to normal data-acquisition operation. The video output remains operative, but with a more limited and fixed view because of the resolution limitation of RS-170 video. Although this view is sufficient to cover the image from a small CCD array in its entirety, it will not cover all the pixels from a large array. Instead, a subset from the center of the image will be shown. For example, in the case of the Kodak KAF-1400 (1317 x 1035), the monitor would display the 756×486 area from the center of the CCD image as shown in Figure 3.
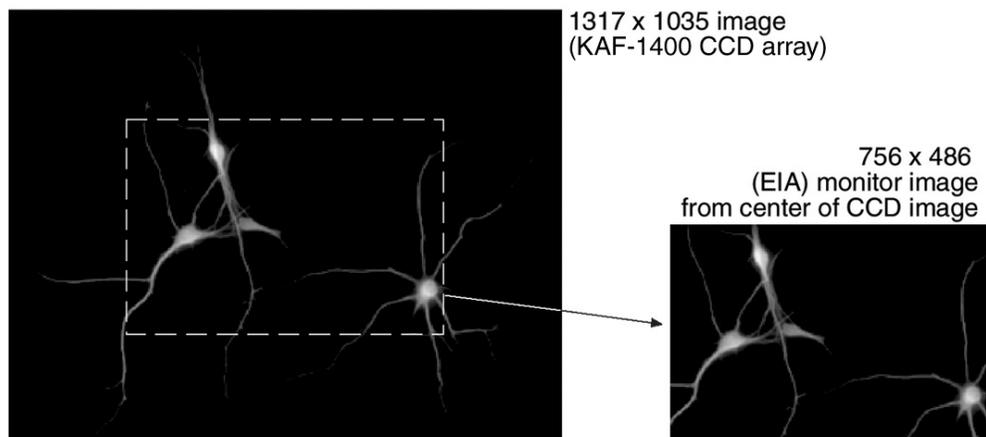
Figure 3. Monitor Display of CCD Image Center Area

In post-acquisition processing the WinView/32 ROI (Region of Interest) capability allows any portion of an acquired image to be displayed on the computer monitor.

Again, note that the described video output behavior applies specifically for the WinView/32 software only. Other application software may provide different video output capabilities.

EXT SYNC BNC connector: This TTL input, which has a 10 kΩ pullup resistor, allows data acquisition and readout to be synchronized with external events. In the External Sync mode, readout is initiated when the signal (typically a pulser trigger output) applied to the Ext Sync connector is detected. Through software you can select either positive or negative edge triggering (default = negative). See *Chapter 5*, *Timing Modes* for detailed information.

Note: There are three sync modes, **Free Run**, **External Sync** and **Internal Sync** selectable via software (WinView/32 Experiment Setup **Timing** tab page). **Internal Sync** mode operation, which does not require a connection to **Ext Sync**, is only available if a PTG Timing Generator is installed. If the timing generator is a DG535, the **D** output of the DG535's **D** output is applied to **Ext Sync** to initiate readout.

$\overline{\text{SCAN}}$ **BNC connector:** In WinView/32 or WinSpec/32 (ver. 2.4 and higher) the signal ($\overline{\text{SCAN}}$ (NOTSCAN) or SHUTTER) provided at this connector is software-selectable. The default is SHUTTER.

Note: When the signal at the $\overline{\text{SCAN}}$ connector is software-selectable, the Logic Out output on the Controller/Camera tab page (Figure 4) indicates the selected signal, either SHUTTER or NOTSCAN. If the selection function isn't present in the software, you may have an older controller and an internal jumper must be

Figure 4. WinView/32 Controller/Camera Setup Tab Page

moved to change the selection. Contact the factory (see page 114) Customer Support Dept. for information on how to change the jumper setting. *Because the default jumper selection is SHUTTER, used to inhibit the pulser/timing generator, it is unlikely that the selection will require changing.*

NOTSCAN reports when the controller is finished reading out the CCD array. **NOTSCAN** is high when the CCD array is not being scanned, then drops low when readout begins, returning to high when the process is finished.

SHUTTER, the default selection, reports when the shutter is opened and can be used to synchronize external shutters. **SHUTTER** is low when the shutter is closed and goes high when the shutter is activated, dropping low again after the shutter closes. As shown in Figure 5, except that the signal includes cleaning activity and t_c, the shutter compensation time (time allowed for the shutter to close), the two signals are similar.

t_{exp} = Exposure Time

t_R = Readout Time

t_c = Shutter Compensation Time

Figure 5. NOTSCAN and SHUTTER Signals

Note: In frame-transfer operation, where the exposure cycle and readout cycle overlap, the timing changes as discussed in Chapter 5 and the system would not ordinarily include an operating shutter.

When the ST-133 is controlling a Princeton Instruments intensified camera[*], SHUTTER has other functions. If shutter-mode operation is selected at the IIC-100, IIC-200 or MCP-100 and there is no signal applied to the **SHUTTER IN** connector of the IIC-100, IIC-200 or MCP-100, the intensifier is biased on continuously and the camera "sees light" for as long as the high voltage is applied. If the ST-133's SHUTTER output is applied to the **SHUTTER IN** connector of the IIC-100, IIC-200 or MCP-100, the intensifier can be turned ON or OFF in much the same way as it is in gated operation, but at slower speeds, allowing exposures from 50 μs to 2.3 hours to be set from software.

In gated operation it is desirable that the intensifier be biased off when the array is being read out to prevent artifacts from being coupled into the video from the high-voltage switching. The SHUTTER signal normally provides this function. With an FG-100 Pulser, this signal would be applied to the pulser's **Enable** input. With a PG-200 Pulser, it would be applied to the pulser's **INHIBIT** input. With a DG535 Timing Generator, the SHUTTER signal is applied to the DG535's **Inhibit** input.

READY BNC connector: After a Start Acquisition command, this output changes state on completion of the array cleaning cycles that precede the *first* exposure. Initially high, it goes low to mark the beginning of the *first* exposure. In free run operation it remains low until the system in halted. If a specific number of frames have been programmed, it remains low until all have been taken, then returns high.

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[*] SHUTTER is not required to inhibit the intensifier if using a PI-MAX camera controlled by an ST-133 equipped with a PTG. With this combination, the inhibit function is accomplished by selecting the Internal Sync mode (WinView/32 or WinSpec/32; **Acquisition| Experiment Setup|Timing|Timing Mode** selection).

F and S Zero adjustments: These 10-turn potentiometers control the offset values of the Fast (F) and Slow (S) A/D converters. The offset is a voltage that is added to the signal to bring the A/D output to a non-zero value, typically 50-100 counts. This offset value ensures that all the true variation in the signal can really be seen and not lost below the A/D "0" value. Since the offset is added to the signal, these counts only minimally reduce the range of the signal to a value in the range of 50-100 counts lower. Adjusting a potentiometer clockwise increases the counts while rotating it counterclockwise decreases the counts. For controllers with only one A/D converter (F), the second pot (S) will not be activated.

Note that the offset is preadjusted for optimum system performance at the factory and should not normally need adjusting. However, to accommodate the widest possible range of measurement conditions, these adjustments are made user accessible.

If these potentiometers are not present, offset may be software-adjustable.

Caution

Do not adjust the offset values to zero, or some low-level data will be missed.

Detector connector: A cable* that interconnects the Controller and the Camera connects to this 25-pin connector (type DB25). This connector, the cable, and the corresponding connector on the camera are configured so that the cable cannot be installed incorrectly. Note that this cable is secured by a slide-lock mechanism at the end that connects to the controller. The other end will be secured by screws or by a slide-lock as required by the camera. To ensure reliable operation, it is essential that both ends of the cable connector be secured before powering the controller.

WARNING

Always turn the power off at the Controller before connecting or disconnecting a cable that interconnects the camera and controller or serious damage to the CCD may result. This damage is *NOT* covered by the manufacturer's warranty.

Interface Control Module: Depending on your system, either the TAXI or the USB 2.0 Interface Control Module will be installed in the second from the left slot (as you face the rear of the ST-133). This module provides the following functions:

- TTL In/Out Programmable Interface

- Communications Control (TAXI or USB 2.0 protocol)

Note: USB 2.0 protocol is supported by versions 2.5.14 and higher of WinView/32 and WinSpec/32. PTG and USB 2.0 compatibility is supported by versions 2.5.15 and higher.

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* If using a PI-MAX camera with an ST-133 equipped with a PTG, there will be two cables between the Controller and the Camera. The first goes from the **Detector** connector of the Controller to the **Power/Signal** connector of the PI-MAX. The second cable goes from the **Timing Gen** connector of the PTG to the **Timing Gen** connector of the PI-MAX.

TTL IN/OUT connector: **(TAXI and USB 2.0)** This 25-pin connector (type DB25) provides a programmable interface. There are eight input bits and eight output bits that can be written to or polled to provide additional control or functionality. For the IN lines, a bit can be set to the buffered state, resulting in a real-time sample or it can be set to the latched state, where the signal is maintained once set. See Appendix C for a description of the pin assignments and refer to your software manual for calling conventions.

AUX BNC connector: **(TAXI and USB 2.0)** Not currently activated. Reserved for future use.

SERIAL COM connector: **(TAXI)** The cable that goes to the computer connects to this DB9 connector. Its purpose is to provide two-way serial communication between the controller and the computer. When connecting this cable, it is essential that the cable connector locking screws be tightened securely to ensure reliable operation.

If the application requires use of the optional fiber-optic data link to increase the maximum allowable distance between the Camera and the computer, the fiber-optic "pod" would be connected to the **Serial Com** connector with a short length of cable. Then the long-distance cable would be connected to the pod. *A similar fiber-optic pod connection would be required at the computer.*

See *Appendix I, Installing the Computer-Controller Interface,* for detailed information on installing and testing the TAXI serial interface link.

USB 2.0 connector: **(USB 2.0)** The USB cable that goes to the computer connects to this connector. Its purpose is to provide two-way communication between the controller and the computer.

Caution

> To minimize any possible risk to system equipment, we recommend that the interface cable (TAXI or USB) not be connected or disconnected when the system is powered.

Programmable Timing Generator Module: This module should always be located in the third slot. *See Appendix B for a detailed description of the PTG and its operation.* In brief, the PTG module provides the following functions:

Ext. Trig. In: The PTG can be either internally or externally triggered as selected in software. If external triggering is selected, the PTG will be triggered by an externally derived trigger pulse applied to this input. The threshold (range ± 5 V), slope, coupling mode (ac or dc), and input impedance (High or 50 Ω) are selectable in software.

Pre. Trig. In: TTL level used only to start a bracket pulse.

T0: TTL Trigger output coincident with PI-MAX gate. *This output does not need to be connected to PI-MAX.*

Timing Gen: Gate Start/Stop and Bracket signals are provided at this connector. *This output **must** be cabled to the PI-MAX **Timing Gen** connector.*

Aux. Trig. Out: Ac coupled variable delay trigger output for synchronizing other system components with PTG. The host software sets the Delay Time of the auxiliary trigger output with respect to the PTG trigger time. *This output does not need to be connected to PI-MAX.*

Trig. Indicator: LED trigger indicator. 100 ms flash is produced each time the PTG triggers. With repetition rates faster than 10 Hz, indicator glows continuously.

Power Input Module: This module contains the line-cord socket, the Power On/Off switch and two fuses. The power and fuse requirements are printed on the panel above the module. For more detailed information, see *"Power Requirements"* on page 13.

Software Installation

It is necessary to install the application software before the controller can be operated and data acquired. The installation procedure will vary according to the computer type, operating controller, and type of application software. See your software manual for detailed software installation and software operation information.

Imaging Field of View

When used for two-dimensional imaging applications, Princeton Instruments cameras closely imitate a standard 35 mm camera. Since the CCD is not the same size as the film plane of a 35 mm camera, the field of view at a given distance is somewhat different. The imaging field of view is indicated in Figure 6.
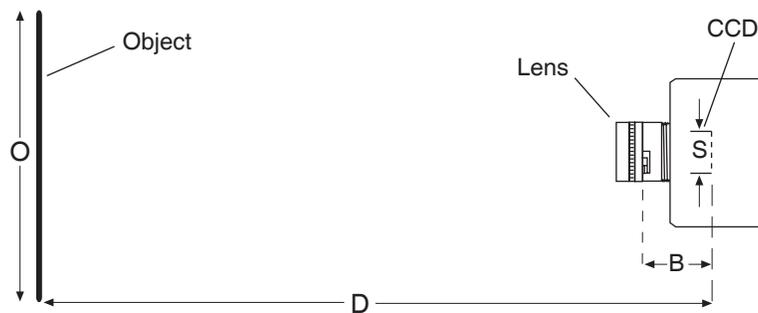
Figure 6. Imaging Field of View

D = distance between the object and the CCD
B = 46.5 mm for F mount; 17.5 mm for C mount
F = focal length of lens
S = CCD horizontal or vertical dimension
O = horizontal or vertical field of view covered at a distance D
M = magnification

The field of view is:

$$O = S/M, \quad \text{where} \quad M = \frac{FD}{(D - B)^2}$$

Summary

This completes *Getting Started*. You should now have a reasonable understanding of how the controller hardware is used. Other topics, which could be quite important in certain situations, are discussed in the following chapters. See the appropriate application software manual for information on using the software to control the controller.

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First Light

Introduction

> **Note:** The instructions in this chapter are for an ST-133 operated with a TE-cooled camera. They do *not* apply to the PI-MAX or LN-cooled cameras. See the PI-MAX system manual for detailed information regarding that camera. In the case of an LN-cooled camera, Dewar and liquid nitrogen considerations make placing the system in operation more complex. Because these issues are not discussed in this manual, if the system includes an LN-cooled camera, refer to the system manual for guidance.

WARNING

> Image intensified CCD cameras (ICCDs) can be destroyed if continuously exposed to light levels higher than twice the A/D saturation level. *If you are using an intensified camera*, it is critical that you *not* establish conditions that could result in damage to the intensifier. High intensity sources such as lasers can even cause spot damage to occur without the protection circuits detecting the overload at all. For simplicity, the following checks are done in the shutter mode in which the intensifier sees light continuously. To prevent damage to the camera, do not turn on the controller power until directed to do so. Also, it is important that the lab lighting be subdued when working with an intensified camera. If a sustained alarm indication occurs when the controller is turned on, either completely cover the intensifier with a black cloth or reduce the laboratory illumination to reduce the light to a safe level still further until safe operating conditions are established. *See your system manual for additional information!*

Imaging

This section provides step-by-step instructions for making an imaging measurement. A section on making a spectroscopy measurement is also provided starting on page 32.

At this point a lens should be mounted on the camera or the camera mounted on a microscope. *See your system manual for lens and camera mounting instructions.* A suggested procedure for operating the system and viewing your first images follows. Note that the intent of this simple procedure is to help you gain basic familiarity with the operation of your ST-133 based system and to demonstrate that it is functioning properly. Once basic familiarity has been established, then operation with other operating configurations, ones with more complex timing modes, can be established as described in Chapter 5, *Timing Modes*. An underlying assumption of this procedure is that a video monitor is available. Although it is possible to dispense with the monitor and simply view the images on the computer monitor's screen, operations such as focusing will be much easier with a video monitor because the displayed data is updated much more quickly and will be as close to current as possible.

To carry out this procedure, it will be necessary to have a basic grasp of the applications software. Refer to your software manual for the required information.

WARNING | **Before You Start**, if your system includes a microscope Xenon or Hg arc lamp, it is **CRITICAL** to turn off all electronics adjacent to the arc lamp, especially your digital camera system and your computer hardware (monitors included) before turning on the lamp power.

Powering up a microscope Xenon or Hg arc lamp causes a large EMF spike to be produced that can cause damage to electronics that are running in the vicinity of the lamp. We advise that you place a clear warning sign on the power button of your arc lamp reminding all workers to follow this procedure. While Roper Scientific has taken great care to isolate its sensitive circuitry from EMF sources, we cannot guarantee that this protection will be sufficient for all EMF bursts. *Therefore, in order to fully guarantee the performance of your system, you must follow this startup procedure.*

Assumptions

The following procedure assumes that

1. You have already set up your system in accordance with the instructions in the system manual.

2. You have read the previous sections of this chapter.

3. You are familiar with the application software.

4. The system is air-cooled. (If your camera is liquid-assisted TE-cooled, liquid-cooled TE, or LN-cooled be sure to review the appropriate setup information in the system manual before proceeding.)

5. The system is being operated in imaging mode.

6. The target is a sharp image, text, or a drawing that can be used to verify that the camera is "seeing" and can be used to maximize focus.

Warnings

WARNING | **Before You Start**, if your system includes a microscope Xenon or Hg arc lamp, it is **CRITICAL** to turn off all electronics adjacent to the arc lamp, especially your digital camera system and your computer hardware (monitors included) before turning on the lamp power.

Powering up a microscope Xenon or Hg arc lamp causes a large EMF spike to be produced that can cause damage to electronics that are running in the vicinity of the lamp. We advise that you place a clear warning sign on the power button of your arc lamp reminding all workers to follow this procedure. While Roper Scientific has taken great care to isolate its sensitive circuitry from EMF sources, we cannot guarantee that this protection will be sufficient for all EMF bursts. *Therefore, in order to fully guarantee the performance of your system, you must follow this startup procedure.*

Getting Started

1. If the system cables haven't as yet been installed, connect them as follows (system power off). *See Figure 7.*

    *   Connect the 25-pin cable from the **DETECTOR** connector on the Analog/Control module panel to the mating connector at the camera. Be sure to secure the cable at both ends.

    *   Connect one end of the interface cable to the **SERIAL COM** or **USB 2.0** connector on the Interface Control module panel. Connect the other end to the computer interface as described in Appendix I. Be sure to secure both ends of the cable.

    *   Connect the line cord from the Power Input assembly on the back of the controller to a suitable source of AC power.

2. Mount a test target in front of the camera.

3. If you haven't already done so, install a lens on the camera or connect it to your microscope or other system optics, whichever applies. *See the manual for your particular camera.* The initial lens settings aren't important but it may prove convenient to set the focus to approximately the anticipated distance and to begin with a small aperture setting.
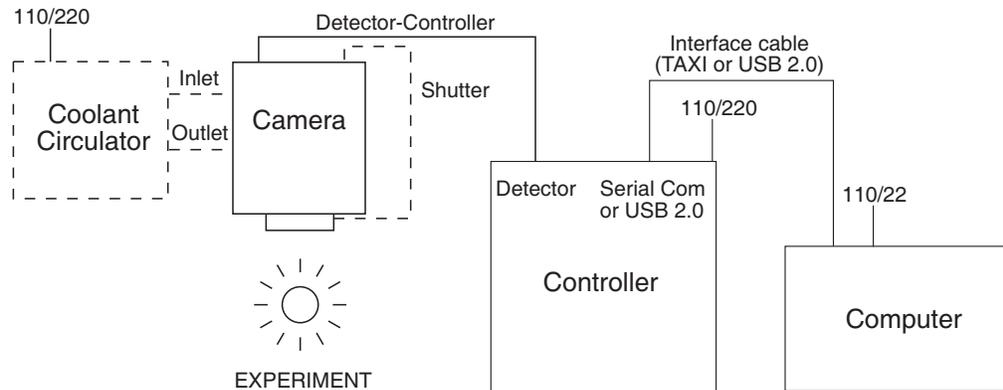
Figure 7. System Connection Diagram (TE Camera)

4. If the TE-cooled camera requires coolant, connect a source of liquid coolant. For purposes of these checks, ordinary tap water will be fine. *Liquid cooling may be necessary with TE cameras (some CCDs, such as the SITe 512x512, don't operate correctly unless cooled to approximately -40°C.) With liquid cooling you will be able to cool TE cameras to -50°C. Without liquid cooling, a TE camera can only lock to -5°C, unless it is a model having forced air cooling, in which case temperature lock down to -40°C (-90°C for the XTE) can be achieved.*

5. Turn on the controller power.

    Notes:

    1. A camera overload alarm may sound briefly and then stop. This is normal and is not a cause for concern. However, if the alarm sounds continuously, even with no light entering the camera, something is wrong. Turn off the power and contact the factory for guidance.

2. With USB 2.0, the controller must be turned on before WinView/32 or WinSpec/32 is opened and WinView/32 or WinSpec/32 must be closed before the controller is turned off.

6. Turn on the computer power.

7. Start the application software.

    Note: If using software other than WinView/32 or WinSpec/32, these instructions will have to be appropriately adapted.

8. If the camera requires coolant, start the coolant flow or fill the LN Dewar.

9. Block light from the lens.

Setting the Parameters

Note: The following procedure is based on WinView/32: you will need to modify it if you are using a different application. Basic familiarity with the WinView/32 software is assumed. If this is not the case, you may want to review the software manual or have it available while performing this procedure.

Set the software parameters as follows:

Environment dialog (Setup|Environment): Verify that the DMA Buffer size is 8 Mbytes (min.). Large arrays may require a larger buffer size. If you change the buffer size, you will have to *reboot the computer* for this memory allocation to be activated, and then restart WinView.

Controller|Camera tab page (Setup|Hardware): Controller and Detector parameters should be set automatically to the proper values for your system. However, you can click on the **Load Defaults From Controller** button on this tab page to load the default settings.

- **Use PVCAM:** If you are using the USB 2.0 interface, verify that the box is checked.
- **Controller type:** ST-133
- **Controller version:** 3 or higher
- **Camera type:** Select the array installed in your camera.
- **Shutter type:** None, Large, or Remote (system dependent).
- **Readout mode:** Full frame.

Detector Temperature (Setup|Detector Temperature…): -40°C for air-cooled. When the array temperature reaches the set temperature, the green **Temp Lock** LED on the rear of the ST-133 will light and there will be a **locked** indication at the computer monitor. Note that some overshoot may occur. This could cause temperature lock to be briefly lost and then quickly re-established. If you are reading the actual temperature reported by the application software, there may be a small difference between the set and reported temperature when lock is established. This is normal and does not indicate a system malfunction. Once lock is established, the temperature will be stable to within ±0.05°C.

Interface tab page (Setup|Hardware): High Speed PCI (or PCI(Timer))
Note: This tab page is not available if you are using the USB 2.0 interface.

Cleans and Skips tab page (Setup|Hardware): Default

Experiment Setup Main tab page (Acquisition|Experiment Setup…):

- **Exposure Time:** 100 ms

- **Accumulations & Number of Images:** 1

Experiment Setup ROI tab page (Acquisition|Experiment Setup…): Use this function to define the region of interest (ROI).

- **Imaging Mode:** Selected

- Clicking on **Full** loads the full size of the chip into the edit boxes.

Experiment Setup Timing tab page (Acquisition|Experiment Setup…):

- **Timing Mode:** Free Run

- **Shutter Control:** Normal

- **Safe Mode vs. Fast Mode:** Safe

Acquiring Data

1. If you are using WinView/32 and the computer monitor for focusing, select **Focus** from the **Acquisition** menu. Successive images will be sent to the monitor as quickly as they are acquired.

2. Adjust the lens aperture, intensity scaling, and focus for the best image as viewed on the computer monitor. Some imaging tips follow:

- Begin with the lens blocked off and then set the lens at the smallest possible aperture (largest f-stop number).

- Make sure there is a suitable target in front of the lens. An object with text or graphics works best. If working with a microscope, use any easily viewed specimen.

- Adjust the intensity scaling and lens aperture until a suitable setting is found. An initial intensity scaling setting of 4096 (for a 12-bit A/D) or 65536 (for a 16-bit A/D) assures that the image won't be missed altogether but could be dim. Once you've determined that the image is present, select a lower setting for better contrast. Check the brightest regions of the image to determine if the A/D converter is at full-scale. *A 12-bit A/D is at full scale when the brightest parts of the image reach an intensity of 4095. A 16-bit A/D is at full scale when the brightest parts of the image reach an intensity of 65535.*Adjust the aperture to where it is just slightly smaller (higher f-stop) than the setting where maximum brightness on any part of the image occurs.

- Set the focus adjustment of the lens for maximum sharpness in the viewed image.

- In the case of a camera with an F-mount, the camera lens adapter itself also has a focus adjustment. If necessary, this focus can be changed to bring the image into range of the lens focus adjustment. Refer to the system manual for instructions on how to do this.

3. After you have focused the camera, you can stop **Focus** mode, continue **Focus** mode, begin **Acquire** mode, or wait for the CCD to reach the operating temperature before going to **Acquire** mode.

4. If the array is cooled by LN, empty the Dewar before turning off the controller. If a coolant circulator or a chiller/circulator is being used to cool the array, stop the flow before turning off the controller.

Note: Exposing the CCD to bright light (10× saturation) when cold (<-70°C) will cause the dark current in the exposed pixels to be 3 to 10 times higher than normal for that operating temperature. This effect is due to the formation of temporary traps. The effect can be reversed by allowing the camera to warm up to room temperature.

Spectroscopy

The following paragraphs provide step-by-step instructions for placing your spectroscopy system in operation the first time. The intent of this simple procedure is to help you gain basic familiarity with the operation of your system and to demonstrate that it is functioning properly. Once basic familiarity has been established, then operation with other operating configurations, ones with more complex timing modes, can be performed. An underlying assumption for the procedure is that the detector is to be operated with a spectrograph such as the Acton SpectraPro® 300i (SP300i) on which it has been properly installed. *See your system manual for mounting instructions.* A suitable light source, such as a mercury pen-ray lamp, should be mounted in front of the entrance slit of the spectrograph. Any light source with line output can be used. *Standard fluorescent overhead lamps have good calibration lines as well.* If there are no "line' sources available, it is possible to use a broadband source such as tungsten for the alignment. If this is the case, use a wavelength setting of 0.0 nm for alignment purposes.

Note: If you purchased an optical-fiber adapter and cable, install them only after the regular alignment procedure has been successfully completed. Consult the Optical Fiber Adapter manual for specific instructions.

In a typical spectrograph, light enters the entrance slit and is collected by a collimating mirror. Collimated light strikes the grating and is dispersed into individual wavelengths (colors). Each wavelength leaves the grating at a different angle and is reimaged by a focusing mirror onto the intensifier photocathode at the exit focal plane. Essentially, what a spectrograph does is to form an image of the entrance slit in the exit focal plane with each position in the plane representing a different wavelength. As each wavelength images at a different horizontal position, the spectrum of the input light is spread across the CCD. Individual wavelengths focused at different horizontal positions along the exit port of the spectrograph are detected simultaneously. Rotating the diffraction grating scans wavelengths across the CCD, allowing the intensity at individual wavelengths to be readily measured.

Assumptions

The following procedure assumes that

1. You have already set up your system in accordance with the instructions in the system manual.

2. You have read the previous sections of this chapter.

3. You are familiar with the application software.

4. The system is air-cooled. (If your camera is liquid-assisted TE-cooled, liquid-cooled TE, or LN-cooled be sure to review the appropriate setup information in the system manual before proceeding.)

5. The system is being operated in spectroscopy mode.

6. An entrance slit shutter is not being controlled by the ST-133.

Getting Started

1. If the system cables haven't as yet been installed, connect them as follows (system power off). *See Figure 8.*

   - Connect the 25-pin cable from the **DETECTOR** connector on the Analog/Control module panel to the mating connector at the camera. Be sure to secure the cable at both ends.

   - Connect one end of the interface cable to the **SERIAL COM** or **USB 2.0** connector on the Interface Control module panel. Connect the other end to the computer interface as described in Appendix I. Be sure to secure both ends of the cable.

   - Connect the line cord from the Power Input assembly on the back of the controller to a suitable source of AC power.
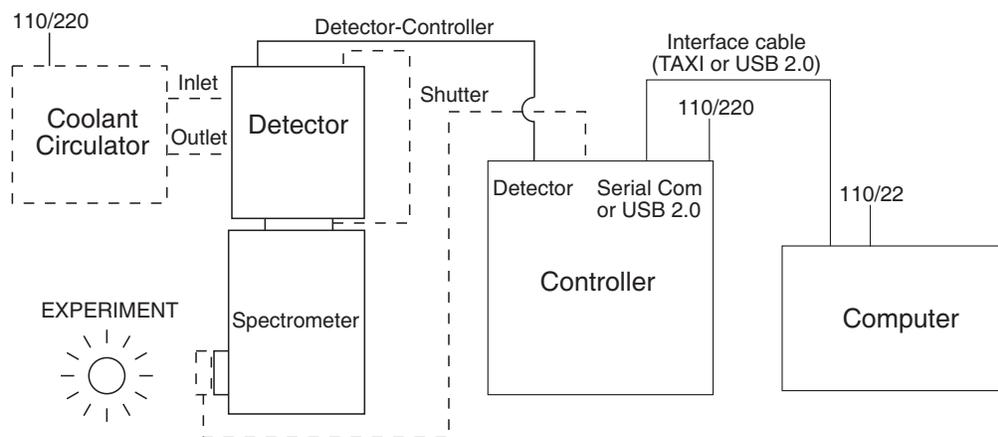
Figure 8. System Connection Diagram (TE Camera and Spectrometer)

2. Set the spectrometer entrance slit width to minimum (10 µm if possible).

3. If the TE-cooled camera requires coolant, connect a source of liquid coolant. For purposes of these checks, ordinary tap water will be fine. *Liquid cooling may be necessary with TE cameras (some CCDs, such as the SITe 512x512, don't operate correctly unless cooled to approximately -40°C.) With liquid cooling you will be able to cool TE cameras to -50°C. Without liquid cooling, a TE camera can only lock to*

-5°C, unless it is a model having forced air cooling, in which case temperature lock down to -40°C (-90°C for the XTE) can be achieved.

4. Turn on the controller power.

    Notes:

    1. A camera overload alarm may sound briefly and then stop. This is normal and is not a cause for concern. However, if the alarm sounds continuously, even with no light entering the camera, something is wrong. Turn off the power and contact the factory for guidance.

    2. With USB 2.0, the controller must be turned on before WinView/32 or WinSpec/32 is opened and WinView/32 or WinSpec/32 must be closed before the controller is turned off.

5. Turn on the computer power.

6. Start the application software.

    Note: If using software other than WinSpec/32, these instructions will have to be appropriately adapted.

7. Start the coolant flow or fill the LN Dewar.

Setting the Parameters

Note: The following procedure is based on WinSpec/32: you will need to modify it if you are using a different application. Basic familiarity with the WinSpec/32 software is assumed. If this is not the case, you may want to review the software manual or have it available while performing this procedure.

Set the software parameters as follows:

Environment dialog (Setup|Environment): Verify that the DMA Buffer size is 8 Mbytes (min.). Large arrays may require a larger buffer size. If you change the buffer size, you will have to *reboot the computer* for this memory allocation to be activated, and then restart WinSpec.

Controller|Camera tab page (Setup|Hardware): Controller and Detector parameters should be set automatically to the proper values for your system. However, you can click on the **Load Defaults From Controller** button on this tab page to load the default settings.

- **Use PVCAM:** If you are using the USB 2.0 interface, verify that the box is checked.

- **Controller type:** ST-133

- **Controller type:** ST-133

- **Controller version:** 3 or higher

- **Camera type:** Select the array installed in your detector.

- **Shutter type:** None or Remote.

- **Readout mode:** Full frame.

Detector Temperature (Setup|Detector Temperature…): -40°C for air-cooled. When the array temperature reaches the set temperature, the green **Temp Lock** LED on the rear of the ST-133 will light and there will be a **locked** indication at the computer monitor. Note that some overshoot may occur. This could cause temperature lock to be briefly lost and then quickly re-established. If you are reading the actual temperature reported by the application software, there may be a small difference between the set and reported temperature when lock is established. This is normal and does not indicate a system malfunction. Once lock is established, the temperature will be stable to within ±0.05°C.

Interface tab page (Setup|Hardware): High Speed PCI (or PCI(Timer))
   Note: This tab page is not available if you are using the USB 2.0 interface.

Cleans and Skips tab page (Setup|Hardware): Default

Experiment Setup Main tab page (Acquisition|Experiment Setup…):

- **Exposure Time:** 100 ms

- **Accumulations & Number of Images:** 1

Experiment Setup ROI tab page (Acquisition|Experiment Setup…): Use this function to define the region of interest (ROI).

- **Spectroscopy Mode:** Selected

- Clicking on **Full** loads the full size of the chip into the edit boxes.

Experiment Setup Timing tab page (Acquisition|Experiment Setup…):

- **Timing Mode:** Free Run

- **Shutter Control:** Normal

- **Safe Mode vs. Fast Mode:** Safe

Focusing

The mounting hardware provides two degrees of freedom, focus and rotation. In this context, focus means to physically move the detector back and forth through the focal plane of the spectrograph. The approach taken is to slowly move the detector in and out of focus and adjust for optimum while watching a live display on the monitor, followed by rotating the detector and again adjusting for optimum. The following procedure, which describes the focusing operation with an Acton 300I spectrograph, can be easily adapted to other spectrographs.

1. Mount a light source such as a mercury pen-ray type in front of the entrance slit of the spectrograph. Any light source with line output can be used. *Standard fluorescent overhead lamps have good calibration lines as well.* If there are no "line" sources available, it is possible to use a broadband source such as tungsten for the alignment. If this is the case, use a wavelength setting of 0.0 nm for alignment purposes.

2. With the spectrograph properly connected to the controller, turn the power on, wait for the spectrograph to initialize. Then set it to 435.8 nm if using a mercury lamp or to 0.0 nm if using a broadband source.

> **Hint:** Overhead fluorescent lights produce a mercury spectrum. Use a white card tilted at 45 degrees in front of the entrance slit to reflect overhead light into the spectrograph. Select 435.833 as the spectral line.

3. Set the slit to 25 µm. *If necessary, adjust the Exposure Time to maintain optimum (near full-scale) signal intensity.*

4. Slowly move the detector in and out of focus. You should see the spectral line go from broad to narrow and back to broad. Leave the detector set for the narrowest achievable line. You may want to use the **Focus Helper** function (**Process|Focus Helper…**) to determine the narrowest line width: it can automatically locate peaks and generate a report on peak characteristics during live data acquisition (see the WinSpec/32 on-line help for more information).

   Note that the way focusing is accomplished depends on the spectrograph, as follows:

   - **Long focal-length spectrographs such as the Acton 300i:** The mounting adapter includes a tube that slides inside another tube to move the detector in or out as required to achieve optimum focus.

   - **Short focal-length spectrographs:** There is generally a focusing mechanism on the spectrograph itself which, when adjusted, will move the optics as required to achieve proper focus.

   - **No focusing adjustment:** If there is no focusing adjustment, either provided by the spectrograph or by the mounting hardware, then the only recourse will be to adjust the spectrograph's focusing mirror.

5. Next adjust the rotation. You can do this by rotating the detector while watching a live display of the line. The line will go from broad to narrow and back to broad. Leave the detector rotation set for the narrowest achievable line.

   Alternatively, take an image, display the horizontal and vertical cursor bars, and compare the vertical bar to the line shape on the screen. Rotate the detector until the line shape on the screen is parallel with the vertical bar.

> **Note:** When aligning other accessories, such as fibers, lenses, optical fiber adapters, first align the spectrograph to the slit. Then align the accessory without disturbing the detector position. The procedure is identical to that used to focus the spectrograph (i.e., do the focus and alignment operations while watching a live image).

Summary

This completes *First Light*. If the system functioned as described, you can be reasonably sure it has arrived in good working order. In addition, you should have a basic understanding of how the system hardware is used. Other topics, which are important under certain conditions, are discussed in the following chapters. See the appropriate application software manual for information on using the software to control the system.

Chapter 4

Temperature Control

Introduction

Temperature control is done via software. Once the desired array temperature has been set, the hardware controls the thermoelectric cooling circuits in the camera so as to reduce the array temperature to the set value. On reaching that temperature, the control loop locks to the set temperature for stable and reproducible performance. The green **TEMP LOCK** indicator on the Analog/Control module panel lights to indicate that temperature lock has been reached (temperature stable to within ±0.05°C). If using WinView/32, there will also be a **TEMP LOCK** indication in the **Detector Temperature** dialog box. This on-screen indication allows easy verification of temperature lock in experiments where the computer and controller are widely separated. There is also provision for reading out the actual temperature at the computer so that the cooling progress can be monitored.

Because the control loop is designed to achieve temperature lock as quickly as possible, overshoot may occur. If this happens, the **TEMP LOCK** indicator will light, then extinguish briefly during the overshoot, then light again and remain lighted as stable control is re-established. This is normal behavior and should not be a cause for concern. Should a low temperature be set initially and then a higher one, this overshoot would probably not occur because the temperature control loop doesn't drive the temperature higher, but rather waits passively for temperature rise to occur. Optimum noise performance is achieved by operating at the lowest temperature at which temperature lock can be maintained. Typical values for the lowest temperature can vary over a wide range and will depend on a number of factors, including the camera type, as discussed in the individual system manuals.

With passive cooling alone, at an ambient temperature of 25°C, temperature lock to a temperature in the camera's operating range should typically take about ten minutes. However, the time required to achieve lock can vary over a considerable range, depending on such factors as the camera type, CCD array type, type of cooling, etc. Also, if the lab is particularly warm, achieving temperature lock might take a little longer (30 minutes maximum), or the lowest temperature at which lock can be achieved could be a little higher. Once lock occurs, it's okay to begin focusing. However, you should wait an additional twenty minutes before taking quantitative data so that the system has time to achieve optimum thermal stability.

Cooling (TE, NTE, NTE 2, RTE, XTE, PI-MAX)

These cameras are ordinarily equipped with a multi-stage Peltier type cooler that is thermally coupled to the CCD. This device uses injected current to draw heat away from the CCD surface. The heat is sequentially transferred through the Peltier stages and from there to the outer shell of the camera via a heat transfer block. The method used to remove the heat from the camera depends on the camera type. In the case of RTE (Round Head) cameras, fins on the body of the camera radiate the heat to the surrounding atmosphere. In addition, there is provision for optional air cooling via an accessory fan for enhanced cooling performance. A cooling fan is standard in the PI-MAX camera. Depending on the thermoelectrically-cooled camera body style, it may have air-cooling, liquid cooling, or liquid-assisted cooling in addition to the cooling provided by the Peltier.

Cooling (LN)

LN cameras have several sections. The front enclosure contains the CCD array seated on a cold finger. This finger is in contact with the LN Dewar and has a heater to regulate the CCD temperature. The front enclosure opens into the vacuum jacket that surrounds the internal LN Dewar.

LN cameras use liquid nitrogen to reduce the temperature of the CCD. The liquid nitrogen is stored in a Dewar that is enclosed in a vacuum jacket for minimal external thermal losses. The chip temperature is regulated by a heating element driven by closed-loop proportional control circuitry. A thermal sensing diode attached to the cooling block of the camera monitors the chip temperature. The temperature can be controlled over a 40° to 50° range Celsius. The exact range depends on the CCD device, as indicated in the Table 2.

CCD Model	Approximate Range
1024HER, 1024EHRB	-50°C to -100°C
All other arrays.	-80°C to -120°C

Table 2. Approximate Temperature Range vs. CCD Model

Caution LN-cooled CCDs, because of their low operating temperatures, must *always* be connected to an operating controller. If the controller power is turned off with liquid nitrogen remaining in the Dewar, the CCD will quickly become saturated with charge, which cannot be readily removed without warming the camera to room temperature.

WARNINGS
1. Never remove the camera's front window; ice will form immediately, destroying the array. Operations requiring contact with the device can only be performed at the factory.
2. Never operate the camera cooled without proper evacuation. This could *destroy* the CCD!

Cooling and Vacuum

Many cameras incorporate a vacuum chamber for enhanced cooling performance. With time, there can be a gradual deterioration of the camera's vacuum. This is turn may eventually affect temperature performance to where it may no longer be possible to achieve temperature lock at the lowest temperatures. In the kind of low-light imaging applications for which cooled CCD cameras are so well suited, it is highly desirable to maintain the controller's temperature performance because the lower the temperature, the lower the thermal noise will be and the better the signal-to-noise ratio.

Vacuum deterioration occurs primarily as a result of outgassing occurring in the vacuum chamber. Because outgassing normally diminishes with time, the rate of vacuum deterioration in new cameras will be faster than in older ones. As a result, for example, a camera that has to be repumped after perhaps a year of operation, may not have to be pumped again for several years.

In any case, should you notice a gradual deterioration in temperature control performance indicative of vacuum deterioration, the camera can be repumped. *Contact the factory Technical Support Dept. for information on refreshing the vacuum. See page 114 for contact information.*

WARNING | The CCD array is subject to damage from condensation if exposed to atmospheric moisture when cold. For this reason, the camera should be kept properly evacuated.

Problems

If temperature lock cannot be achieved or maintained, it will be necessary to find and correct the problem to be assured of good measurement results. Possible causes could include:

- The vacuum has deteriorated as described above and needs to be refreshed.

- The connectors of the cable that interconnects the controller and the camera need to be secured (slide-lock latch or screws as required).

- The internal temperature of the camera has gotten too high, such as might occur if the operating environment is particularly warm or if you are attempting to operate at a temperature colder than the specified limit. Both TE and RTE cameras are equipped with a thermal-protection switch that shuts the cooler circuits down if the internal temperature exceeds a preset limit. Typically, camera operation is restored automatically in about ten minutes. Although the thermo-protection switch will protect the camera, you are nevertheless advised to power down and correct the operating conditions that caused the thermal-overload to occur.

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Timing Modes

Introduction

The Princeton Instruments ST-133 Controller has been designed to allow the greatest possible flexibility when synchronizing data collection with an experiment.

The chart to the right lists the timing mode combinations. Use this chart in combination with the detailed descriptions in this chapter to determine the optimal timing configuration.

Mode	Shutter
Free Run	Normal
External Sync	Normal
External Sync	PreOpen
External Sync with Continuous Cleans	Normal
External Sync with Continuous Cleans	PreOpen

Table 3. Camera Timing Modes

Fast Mode or Safe Mode

The WinView/32 Experiment Setup **Timing** tab page allows the user to choose **Fast Mode** or **Safe Mode**. Figure 9 is a flow chart comparing the two modes. In Fast Mode operation, the ST-133 runs according to the timing of the experiment, with no interruptions from the computer. In Safe Mode operation, the computer processes each frame as it is received. The ST-133 cannot collect the next frame until the previous frame has been completely processed.

Fast Mode operation is primarily for collecting "real-time" sequences of experimental data, where timing is critical and events cannot be missed. Once the ST-133 is sent the Start Acquisition command by the computer, all frames are collected without further intervention from the computer. The advantage of this timing mode is that timing is controlled completely through hardware. A drawback to this mode is that the computer will only display frames when it is not performing other tasks. Image display has a lower priority, so the image on the screen may lag several images behind. A second drawback is that a data overrun may occur if the number of images collected exceeds the amount of allocated RAM or if the computer cannot keep up with the data rate.

Safe Mode operation is primarily useful for experiment setup, including alignment and focusing, when it is necessary to have the most current image displayed on the screen. It is also useful when data collection must be coordinated with external devices such as external shutters and filter wheels. As seen in , in Safe Mode operation, the computer controls when each frame is taken. After each frame is received, the camera sends the Stop Acquisition command to the camera, instructing it to stop acquisition. Once that

frame is completely processed and displayed, another Start Acquisition command is sent from the computer to the camera, allowing it to take the next frame. Display is therefore, at most, only one frame behind the actual data collection.

One disadvantage of the Safe mode is that events may be missed during the experiment, since the ST-133 is disabled for a short time after each frame.

Standard Timing Modes

The basic ST-133 timing modes are Free Run, External Sync, External Sync with Continuous Cleans, and Internal Sync (available only if the ST-133 has a PTG installed). These timing modes are combined with the Shutter options to provide the widest variety of timing modes for precision experiment synchronization.

The shutter options available include Normal, PreOpen, Disable Opened or Disable Closed. Disable simply means that the shutter will not operate during the experiment. Disable closed is useful for making dark charge measurements, or when no shutter is present in the controller. PreOpen, available in the External Sync and External Sync with Continuous Cleans modes, opens the shutter as soon as the ST-133 is ready to receive an External Sync pulse. This is required if the time between the External Sync pulse and the event is less than a few milliseconds, the time it takes the shutter to open.

The shutter timing is shown in the timing diagrams that follow. Except for Free Run, where the modes of shutter operation are identical, both Normal and PreOpen lines are shown in the timing diagrams and flow chart.

The timing diagrams are labeled indicating the exposure time (t_{exp}), shutter compensation time (t_c), and readout time (t_R). These parameters are discussed in more detail in Chapter 6.

Safe Mode

Start

Computer programs
camera with exposure
and binning parameters

Start acquisition
command sent from
computer to camera

Cleans performed

1 frame collected
as per timing mode

Stop acquisition
command sent from
computer to camera

Background or
flatfield on?   No

Yes

Background and/or
flatfield correction
performed

Frame displayed

Frames
complete?   No

Yes

Stop

Fast Mode

Start

Computer programs
camera with exposure
and binning parameters

Start acquisition
command sent from
computer to camera

Cleans performed

1 frame collected
as per timing mode

Background or
flatfield on?   No

Yes

Background and/or
flatfield correction
performed

Yes   Frames
complete?

No

During next acquisition
frames are displayed as
time permits

Stop acquisition
command sent from
computer to camera

Stop

Figure 9. Flowcharts of Safe and Fast Mode Operations

Free Run timing

In the Free Run mode the controller does not synchronize with the experiment in any way. The shutter opens as soon as the previous readout is complete, and remains open for the exposure time, t_{exp}. Any External Sync signals are ignored. This mode is useful for experiments with a constant light source, such as a CW laser or a DC lamp. Other experiments that can utilize this mode are high repetition studies, where the number of shots that occur during a single shutter cycle is so large that it appears to be continuous illumination.

Other experimental equipment can be synchronized to the ST-133 controller by using the output signal (software-selectable SHUTTER or NOTSCAN) from the $\overline{\text{SCAN}}$ connector. Shutter operation and the NOTSCAN output signal are shown in Figure 11.
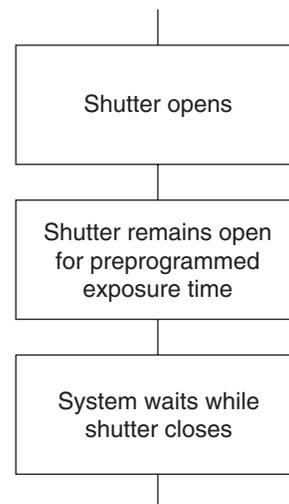

Figure 10. Free Run Timing Chart, part of the chart in Figure 9
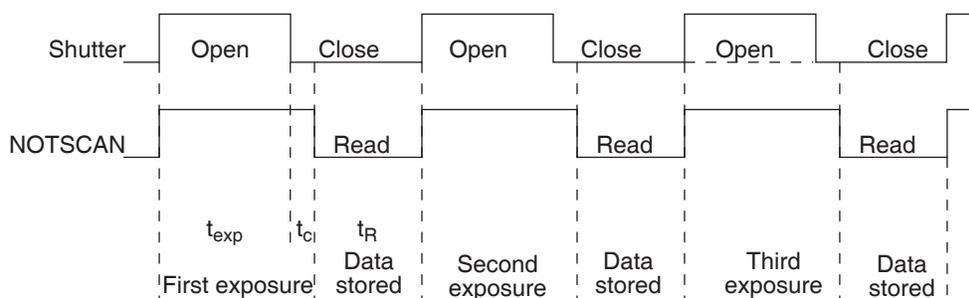

Figure 11. Free Run Timing Diagram

External Sync timing

In this mode all exposures are synchronized to an external source. As shown in the flow chart, Figure 12, this mode can be used in combination with Normal or PreOpen Shutter operation. In Normal Shutter mode, the controller waits for an External Sync pulse, then opens the shutter for the programmed exposure period. As soon as the exposure is complete, the shutter closes and the CCD array is read out. The shutter requires several msec to open completely, depending on the model of shutter. (Shutter compensation time is discussed in Chapter 6.)

Since the shutter requires up to 28 msec to fully open, the External Sync pulse provided by the experiment must precede the actual signal by at least that much time. If not, the shutter will not be open for the duration of the entire signal, or the signal may be missed completely.

Also, since the amount of time from initialization of the experiment to the first External Sync pulse is not fixed, an accurate background subtraction may not be possible for the first readout. In multiple-shot experiments this is easily overcome by simply discarding the first frame.

In the PreOpen Shutter mode, on the other hand, shutter operation is only partially synchronized to the experiment. As soon as the controller is ready to collect data, the shutter opens. Upon arrival of the first External Sync pulse at the ST-133, the shutter remains open for the specified exposure period, closes, and the CCD is read out. As soon as readout is complete, the shutter reopens and waits for the next frame.
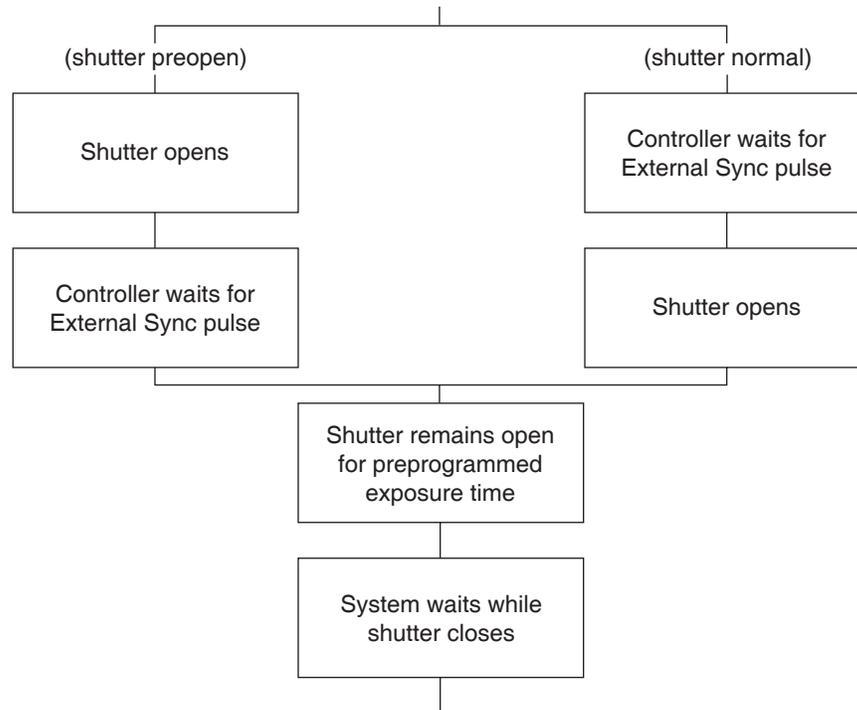

Figure 12. Chart showing Two External Sync Timing Options

The PreOpen mode is useful in cases where an External Sync pulse cannot be provided 5-28 msec before the actual signal occurs. Its main drawback is that the CCD is exposed to any ambient light while the shutter is open between frames. If this ambient light is constant, and the triggers occur at regular intervals, this background can also be subtracted, providing that it does not saturate the CCD. As with the Normal Shutter mode, accurate background subtraction may not be possible for the first frame.

Also note that, in addition to signal from ambient light, dark charge accumulates during the "wait" time (t_w). Any variation in the external sync frequency also affects the amount of dark charge, even if light is not falling on the CCD during this time.

Note: If EXT SYNC is still active at the end of the readout, the hardware will interpret this as a second sync pulse, and so on.
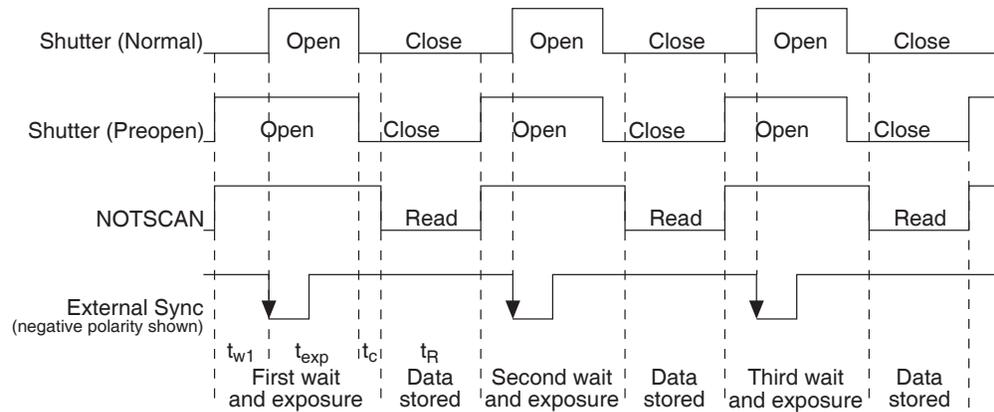
Figure 13. Timing Diagram for the External Sync Mode

External Sync with Continuous Cleans Timing

Another timing mode available with an ST-133 controller is called Continuous Cleans. In addition to the standard "cleaning" of the array, which occurs after the controller is enabled, Continuous Cleans will remove any charge from the array until the moment the External Sync pulse is received.
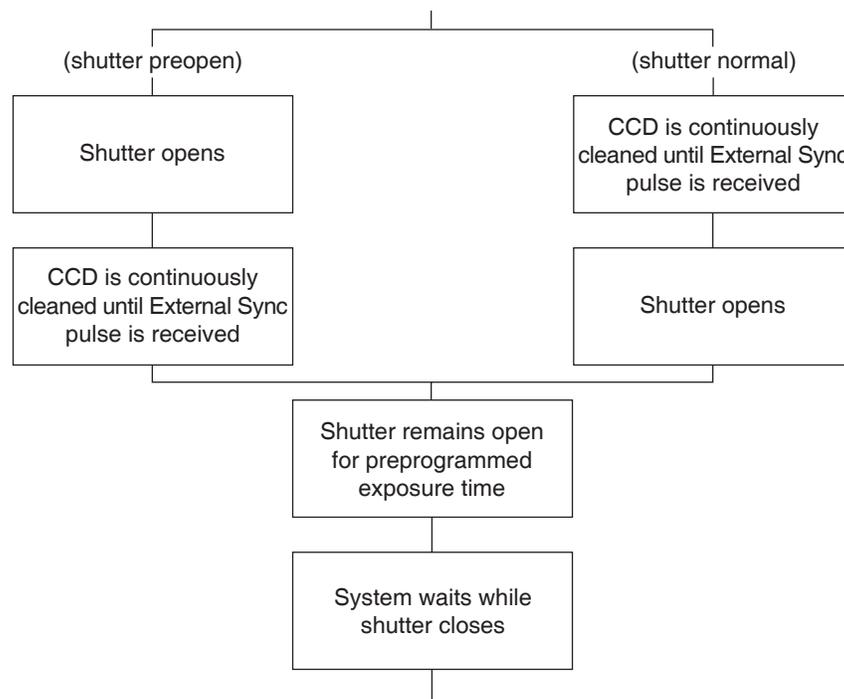

Figure 14. Continuous Cleans Operation Flow Chart

Once the External Sync pulse is received, cleaning of the array stops as soon as the current row is shifted, and frame collection begins. With Normal Shutter operation the shutter is opened for the set exposure time. With PreOpen Shutter operation the shutter is open during the continuous cleaning, and once the External Sync pulse is received the shutter remains open for the set exposure time, then closes. If the vertical rows are shifted midway when the External Sync pulse arrives, the pulse is saved until the row shifting is

completed, to prevent the CCD from getting "out of step." As expected, the response latency is on the order of one vertical shift time, from 1-30 μsec depending on the array. This latency does not prevent the incoming signal from being detected, since photo generated electrons are still collected over the entire active area. However, if the signal arrival is coincident with the vertical shifting, image smearing of up to one pixel is possible. The amount of smearing is a function of the signal duration compared to the single vertical shift time.

Note: If EXT SYNC is still active at the end of the readout, the hardware will interpret this as a second sync pulse, and so on.
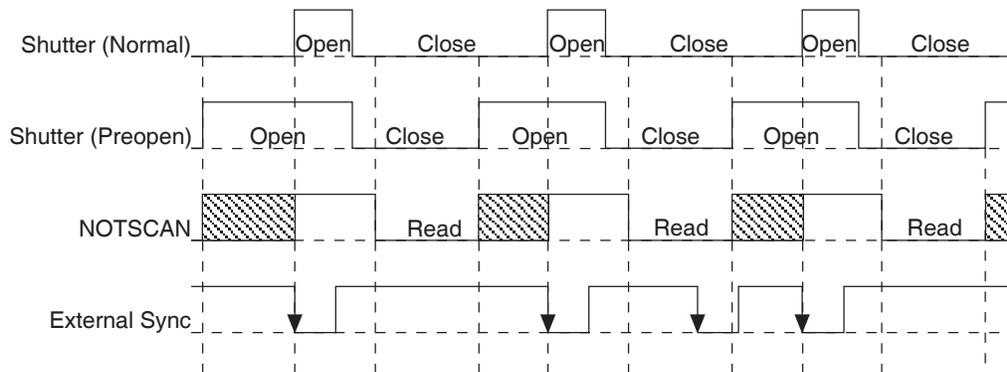

Figure 15. Continuous Cleans Timing Diagram

Internal Sync

Internal Sync operation, in which the synchronization handshake is implemented via the backplane of an ST-133, does not require a connection to the Ext Sync connector. With respect to timing considerations, the mode is very similar to the Ext Sync mode. Note that the Int. Sync. mode is only available if an ST-133 has a PTG installed.

Frame Transfer Mode

In frame transfer operation, half the CCD is used for sensing light and the other half for storage and readout. Not all CCD arrays are capable of readout in this mode, as it requires that charge be shifted independently in the two halves of the array. *See Chapter 6 for a detailed discussion of readout in the frame-transfer mode operation; the primary focus of this section is frame-transfer timing.*

There are two timing options available in frame transfer mode, Free Run and External Sync. Both are similar to their counterparts in full frame (standard) operation, except that in frame transfer operation a shutter is not generally used. Because there is no shutter (or the shutter is only closed after the camera has collected a series of frames), shutter Normal, PreOpen, or Disable have no physical meaning here. The exposure half of the array sees light continuously. The *actual exposure time* is the time between data transfers from the exposure half of the array to the storage half of the array, and may be longer than the programmed exposure, t_{exp}. Data transfer from the exposure half of the array to the storage half occurs very quickly at the start of each read. During the read, the stored data is shifted to the array's output port, the same as in standard operation.

In Free Run frame-transfer mode operation, half the array is exposed for the set exposure time (t_{exp}). Then the data transfer to the storage half of the array takes place, marking the start of the read and the beginning of a new exposure.

In External Sync frame-transfer mode operation, the camera reads out one frame for every External Sync pulse received, providing the frequency of the External Sync pulse doesn't exceed the maximum rate possible with the system. Other than for the first readout, initiated by starting acquisition, a Sync Pulse must be detected before the subsequent readout can occur. If operating without a shutter, the actual exposure time is set by the period of the sync signal. There is one exception, if the programmed exposure time is less than the readout time, then the actual exposure time is simply equal to t_R, the readout time (marked by **NOTSCAN** low). More specifically, if the readout time, t_R, is greater than the sum of t_{w1}, the time the controller waits for the first External Sync pulse, plus t_{exp}, the programmed exposure time, plus t_c, the shutter compensation time, then the actual exposure time will equal t_R. If an External Sync pulse is detected during each read, frames will follow one another as rapidly as possible as shown in Figure 16. *In these figures, Shutter indicates the programmed exposure time. If a shutter were present and active, it would also be the actual exposure time.*

Prior to the first readout, clean cycles are performed on the array. When the software issues a Start Acquisition command, the first readout is generated in hardware and the rapid data transfer from the exposure half of the array to the storage half of the array occurs (marking the beginning of the first exposure). The initial data read are discarded because they are not meaningful. The first exposure continues until the next data transfer, which occurs at the beginning of the next readout, 50 ns after the first readout ends. The data acquired during the first exposure is then read out. This pattern continues for the duration of the experiment so that, during each frame, the data acquired during the previous frame is read out.
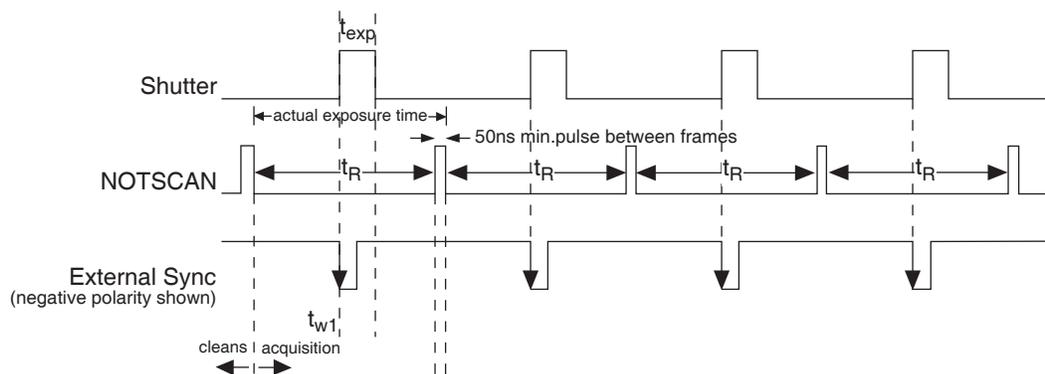

Figure 16. Frame Transfer where $t_{w1} + t_{exp} + t_c < t_R$

Figure 17 shows the case where the programmed storage time is greater than the time required to read out the storage half of the array, that is, where $t_{w1} + t_{exp} + t_c > t_R$. In this case, the programmed exposure time will dominate in determining the actual exposure time. In the situation depicted in Figure 17, the External Sync pulse arrives during the readout. As always, the External Sync pulse must be detected before the next readout can occur. However, there is no requirement as to when it must be applied or even that it be periodic. The timing of the External Sync pulse is entirely at the user's discretion. In Figure 18, the External Sync pulse is shown arriving after the read. Detection of the External Sync pulse enables a new readout to occur on completion $t_{exp} + t_c$.
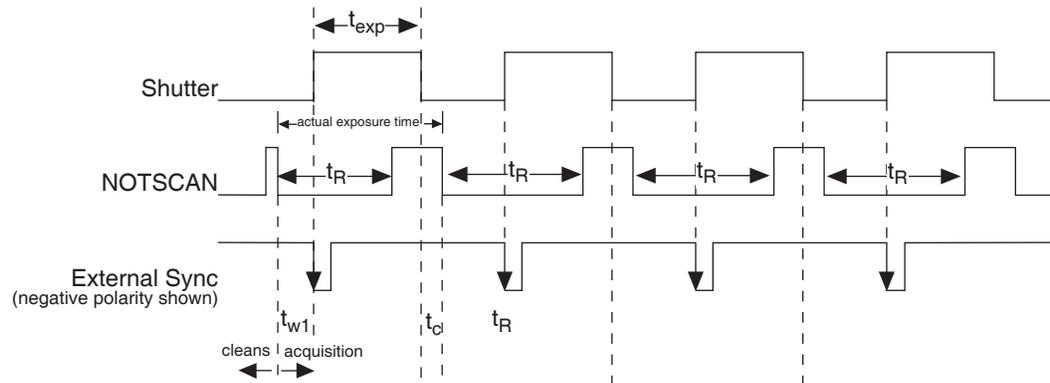
*Figure 17. Frame Transfer where $t_{w1} + t_{exp} + t_c > t_R$*
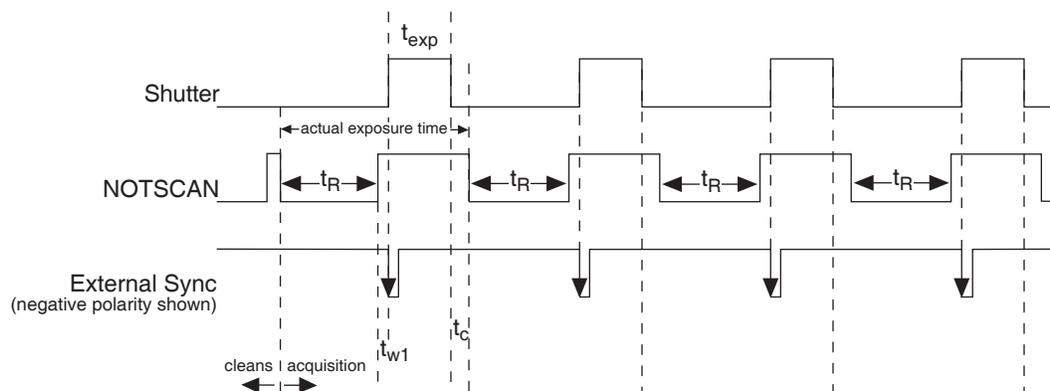
Figure 18. Frame Transfer where Pulse arrives after Readout

Kinetics Mode

Introduction

Kinetics mode uses the CCD to expose and store a limited number of images in rapid succession. The time it takes to shift each line (or row) on the CCD is as short as a few hundred nanoseconds to few microseconds, depending on the CCD. Therefore the time between images can be as short as a few microseconds. Kinetics mode allows frame transfer CCDs to take time-resolved images/spectra.

Note: Kinetics mode is an option, so the controller must be programmed before your order is shipped. If the Kinetics option has been installed in the ST-133, this readout mode will be made available when you select the appropriate camera type on the **Hardware Setup** dialog box.

Below is a simplified illustration of kinetics mode. Returning to our 4×6 CCD example, in this case 2/3 of the array is masked, either mechanically or optically. The shutter opens to expose a 4×2 region. While the shutter remains open, charge is quickly shifted just under the mask, and the exposure is repeated. After a third image is collected the shutter is closed and the CCD is read out. Since the CCD can be read out slowly, very high dynamic range is achieved. Shifting and readout are shown in Figure 19.
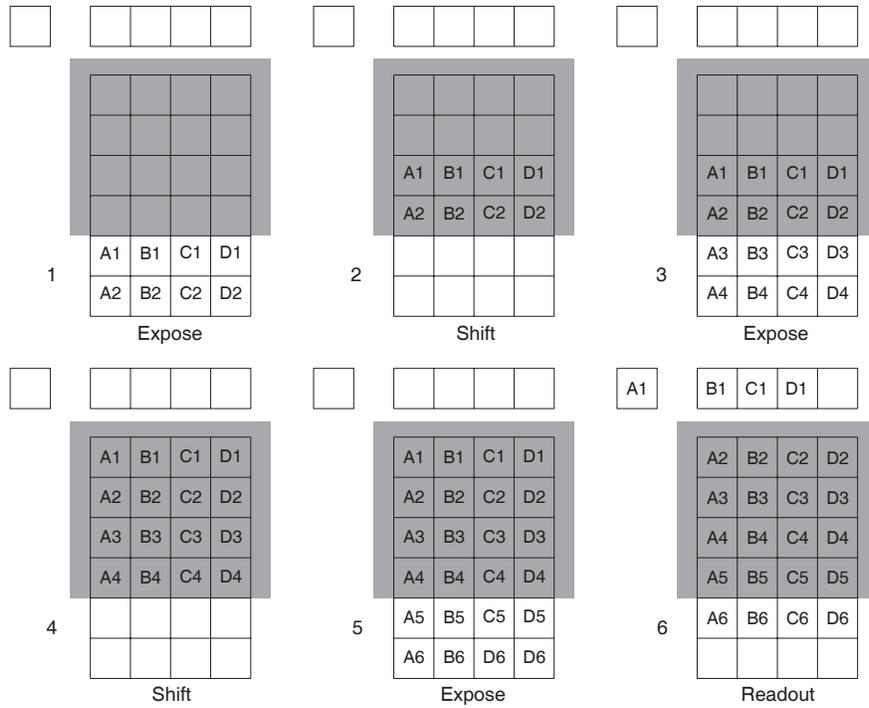
Figure 19. Kinetics Readout

Timing Modes

Kinetics mode has three timing modes: Free Run, Single Trigger, and Multiple Trigger.
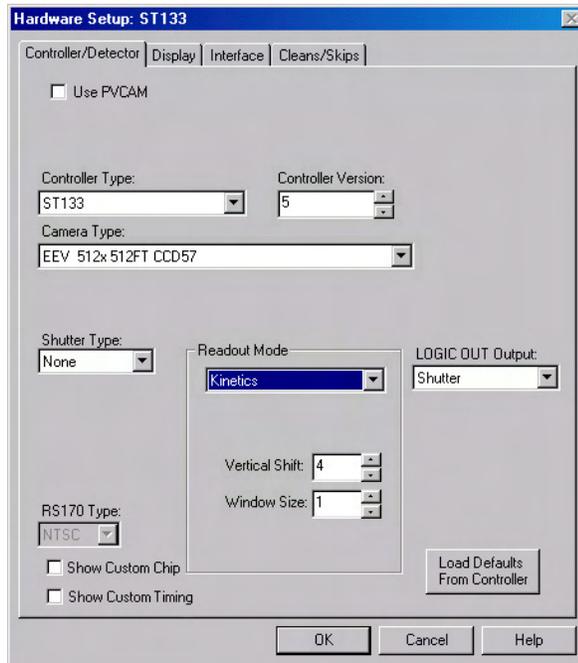

Figure 20. Hardware Setup Dialog Box
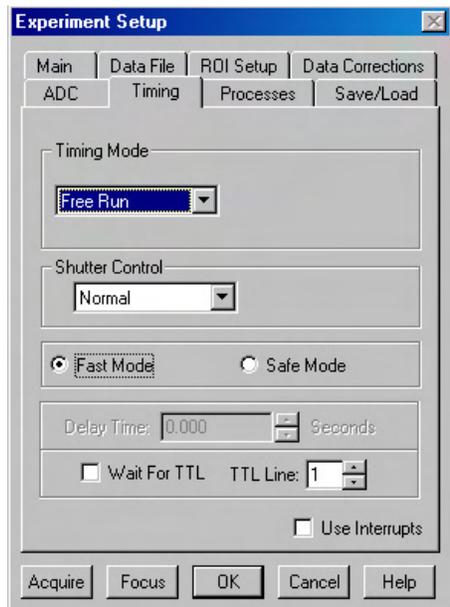
Figure 21. Experiment Setup Dialog Box

Free Run

In the Free Run Kinetics mode, the controller takes a series of images, each with the Exposure time set through the software (in WinView32, the exposure time is set on the **Experiment Setup|Main** tab page). The time between image frames, which may be as short as a few microseconds, is limited by the time required to shift an image under the mask: this interimage time equals the Vertical Shift rate (specified in μsec/row) multiplied by the Window Size (the number of rows allocated for an image frame). The exact number of frames depends on the selected Window Size and is equal to the number of pixels perpendicular to the shift register divided by the Window Size.

Example: Referring to the readout shown in Figure 19, there are 6 pixels perpendicular to the shift register and the Window Size is 2 pixels high. The number of frames is 3. If the Vertical Shift Rate for the CCD is 1.6 μsec/row, the Shift time will be 3.2 μsec per frame.

Integrate signals (SHUTTER) or Readout signals (NOTSCAN) are provided at the $\overline{\text{SCAN}}$ BNC for timing measurements.
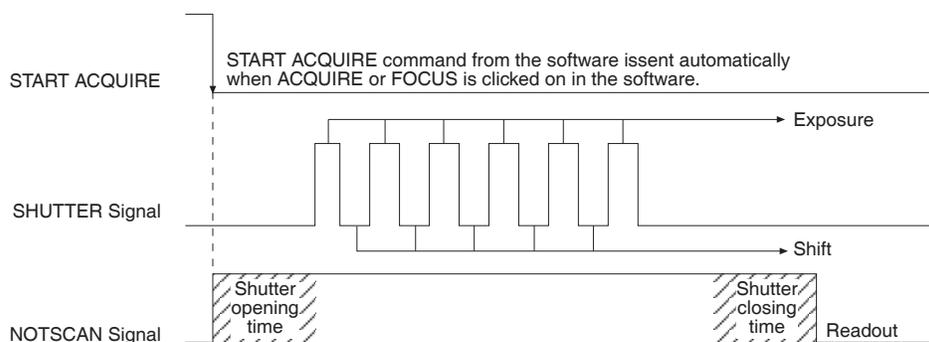
Figure 22. Free Run Timing Diagram

Single Trigger

Single Trigger Kinetics mode takes an entire series of images with each External Trigger Pulse (applied at the Ext. Sync BNC on the control board of ST-133). After the series is complete the shutter closes and the CCD is read out at normal speeds. Once the readout is complete the camera is ready for the next series of exposures. This timing is shown in Figure 23, where a single External trigger pulse is used to collect a burst of 6 frames.
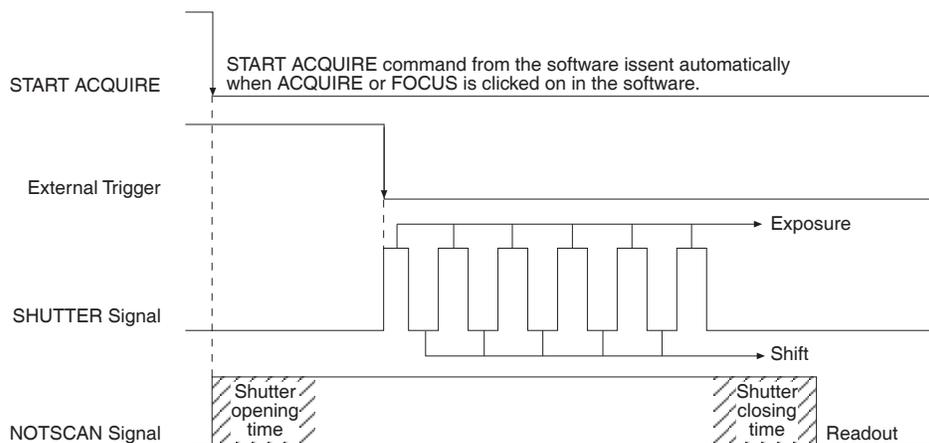
Figure 23. Single Trigger Timing Diagram

Multiple Trigger

Multiple Trigger Kinetics mode takes a single image in the series for each External Sync pulse received by the controller. Once the series is complete the shutter closes and readout begins. Since the shutter is open during the entire series of images, if the External Sync pulses are irregularly spaced then the exposures will be of different lengths. Once the series has been read out the camera is ready for the next series. This timing is shown in Figure 24, where a series of 6 frames is collected with 6 External Sync pulses.
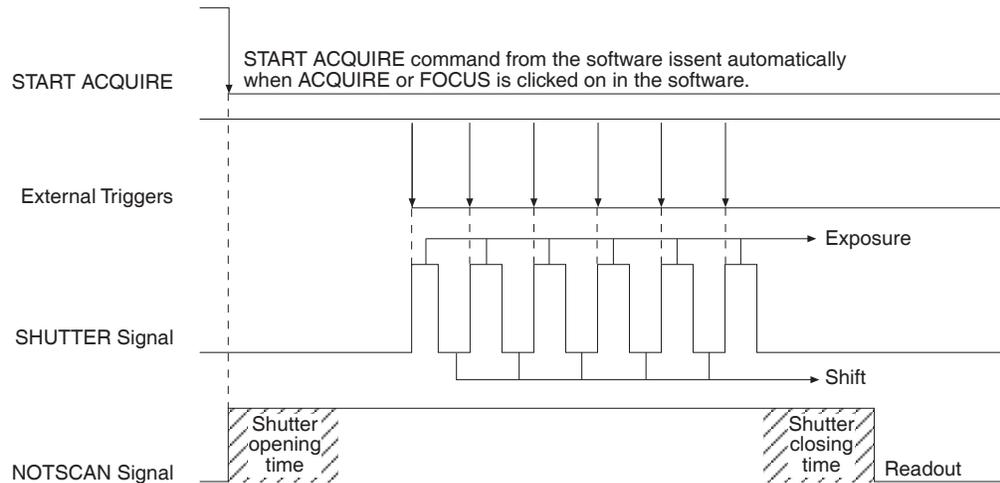

Figure 24. Multiple Trigger Timing Diagram

Chapter 6

Exposure and Readout

Before each image from the CCD array appears on the computer screen, it must first be read, digitized, and transferred to the computer. Figure 25 is a block diagram of the image-signal path.
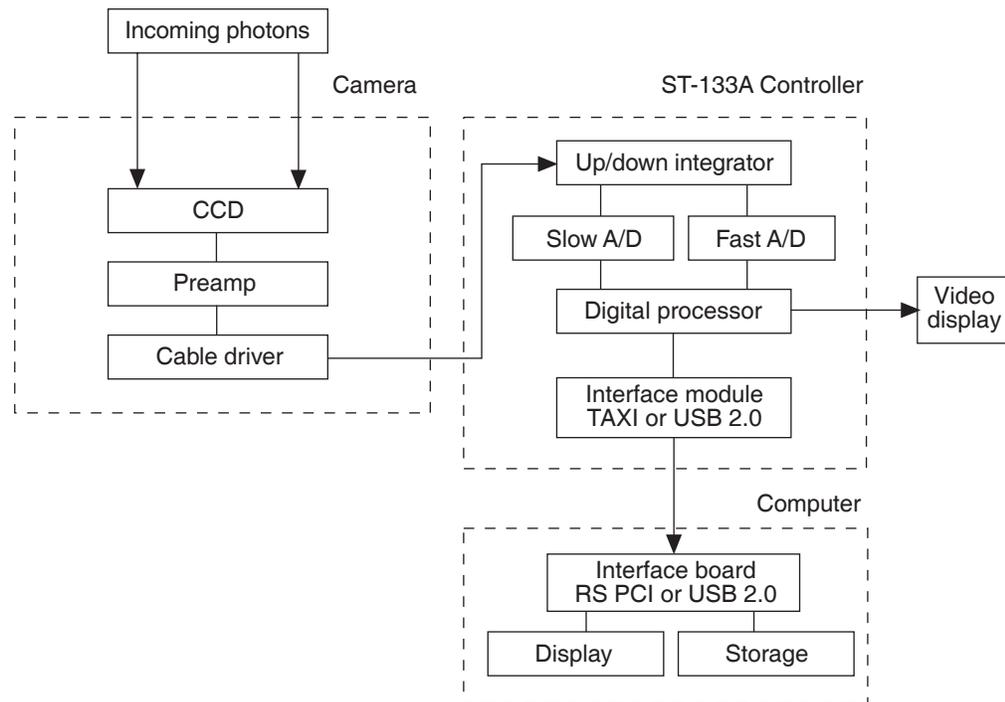
Figure 25. Block Diagram of Light Path in System

The remainder of this chapter describes the exposure, readout, and digitization of the image. Included are descriptions of binning for imaging applications and the specialized ST-133 timing modes.

Exposure

Charge coupled devices can be roughly thought of as a two-dimensional grid of individual photodiodes (called pixels), each connected to its own charge storage "well." Each pixel senses the intensity of light falling on its collection area, and stores a proportional amount of charge in its associated "well." Once charge accumulates for the specified exposure time, the pixels are read out serially.

CCD arrays perform three essential functions: photons are transduced to electrons, integrated and stored, and finally read out. CCDs are very compact and rugged. Unintensified, uncoated CCDs can withstand direct exposure to relatively high light

levels, magnetic fields and RF radiation. They are easily cooled and can be precisely thermostated to within a few tens of millidegrees.

Because CCD arrays, like film and other media, are always sensitive to light, light must not be allowed to fall on the array during readout. Unintensified full-frame CCD cameras like the ST-133 use a mechanical shutter to prevent light from reaching the CCD during readout. ICCD (intensified) cameras use an image intensifier to gate the light on and off.

The software allows the user to set the length of time the camera is allowed to integrate the incoming light. This is called the exposure time. During each scan, the shutter or intensifier is enabled for the duration of the exposure period, allowing the pixels to register light.

Exposure with a Mechanical Shutter

For some CCD arrays, the ST-133 uses a mechanical shutter to control exposure of the CCD. The diagram in Figure 26 shows how the exposure period is measured. The **NOTSCAN** signal, provided at the **SCAN** BNC on the ST-133 Analog/Control panel, can be used to monitor the exposure and readout cycle (t_R). This signal is also shown in Figure 26. The value of t_c is shutter type dependent, and will be configured automatically for cameras shipped with an internal shutter.
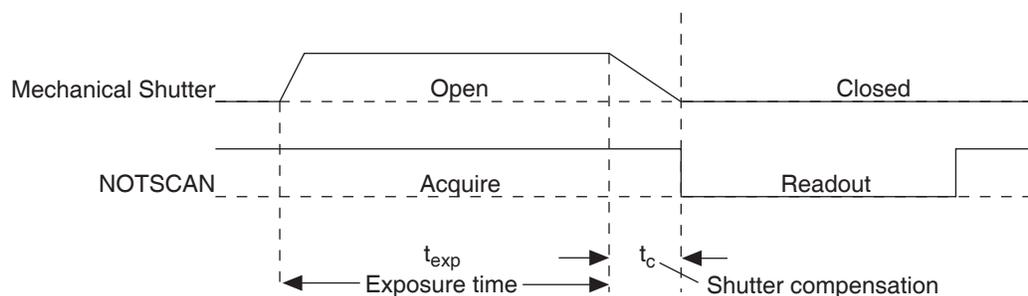

Figure 26. Exposure of the CCD with Shutter Compensation

NOTSCAN is low during readout, high during exposure, and high during shutter compensation time.

Since most shutters behave like an iris, the opening and closing of the shutter will cause the center of the CCD to be exposed slightly longer than the edges. It is important to realize this physical limitation, particularly when using short exposures.

Exposure with an Image Intensifier

Although the standard camera is not intensified, it is possible to connect it to a lens-coupled intensifier, making the following general discussion of intensified operation applicable.

ICCD (intensified) cameras use an image intensifier both to gate light on and off and to greatly increase the brightness of the image. In these cameras the image intensifier detects and amplifies the light, and the CCD is used for readout.

The exposure programmed by software in this case refers to duration of gating of the intensifier. For shorter exposures, a Princeton Instruments pulser is required.

The MCP (microchannel plate) of the intensifier is composed of more than 10^6 individual miniature electron multipliers with an excellent input to output spatial geometric

accuracy. Intensifier gain is varied by adjusting the voltage across the MCP or the voltage across the MCP output and the phosphor. This second parameter is a factory adjustment, as it affects both the gain and the resolution of the intensifier.

Detection of extremely weak Continuous Wave (CW) signals, e.g., luminescence and Raman scattering from solid state samples, is typically limited by the dark current of the intensifier's photocathode, usually referred to as the equivalent brightness intensity (EBI). All standard intensified cameras made by Roper Scientific have the lowest EBI values possible.

Continuous Exposure (no shuttering)

For full-frame CCDs, the standard camera is equipped with an integral shutter. However, inasmuch as it is possible to order the camera without a shutter, the following general discussion of unshuttered operation is provided.

Unlike video rate CCD cameras, slow scan scientific cameras require a shutter to prevent "smearing" of features during readout. This is because during readout, charge is moved horizontally or vertically across the surface of the CCD. If light is falling on the CCD during readout then charge will continue to accumulate, blurring the image along one direction only.

For some experimental applications a shutter is not required because no light falls on the CCD during readout. If the light source can be controlled electronically via the **NOTSCAN** or **SHUTTER** signal (from the $\overline{\text{SCAN}}$ BNC), the CCD can be read out in darkness.

Cameras with frame-transfer capability may be used with or without a shutter. When operating without a shutter, image smearing may occur, depending on the exact nature of the experiment. This effect, caused by light falling on the CCD array as the charge is shifted to the masked area, occurs only if the CCD is illuminated during shifting. In the case of intensified cameras (ICCDs), this effect can be eliminated by using a fast phosphor and gating the intensifier at the same frame rate as the CCD.

The fraction of total signal due to smearing is the ratio of the amount of time spent shifting divided by the exposure time between frames. Faster shifting and/or longer exposure times will minimize this effect. Note that while 1% smear is insignificant in an 8-bit camera (256 gray levels), in a 12-bit camera (over 4,000 gray levels) 1% smearing is over 40 counts, enough to obscure faint features in a high dynamic range image.

Saturation

When signal levels in some part of the image are very high, charge generated in one pixel may exceed the "well capacity" of the pixel, spilling over into adjacent pixels in a process called "blooming." In this case a more frequent readout is advisable, with signal averaging to enhance S/N (Signal-to-Noise ratio) accomplished through the software.

For signal levels low enough to be readout-noise limited, longer exposure times, and therefore longer signal accumulation in the CCD, will improve the S/N ratio approximately linearly with the length of exposure time. There is, however, a maximum time limit for on-chip averaging, determined by either the saturation of the CCD by the signal or the loss of dynamic range due to the buildup of dark charge in the pixels (see below).

Dark Charge

Dark charge or dark current is the thermally induced buildup of charge in the CCD over time. The statistical noise associated with this charge is known as dark noise,. Dark charge values vary widely from one CCD array to another and are exponentially temperature dependent. At the typical operating temperature of a camera dark charge may be reduced by a factor of ~2 for every 6º reduction in temperature. In the case of cameras that have MPP type arrays, the average dark charge is extremely small. However, the dark-charge distribution is such that a significant number of pixels may exhibit a much higher dark charge, limiting the maximum practical exposure. Dark charge effect is more pronounced in the case of cameras having a non-MPP array.

With the light into the camera completely blocked, the CCD will collect a dark charge pattern, dependent on the exposure time and camera temperature. The longer the exposure time and the warmer the camera, the larger and less uniform this background will appear. Thus, to minimize dark-charge effects, you should operate with the lowest CCD temperature possible.

Notes:

1. Do not be concerned about either the baseline (DC) level of this background or its shape unless it is very high, i.e., > 1000 counts with 16-bit A/D or > 400 counts with a 12-bit A/D. What you see is not noise. It is a fully subtractable readout pattern. Each CCD has its own dark charge pattern, unique to that particular device. Simply acquire and save a dark charge "background image" under conditions identical to those used to acquire the "actual" image. Subtracting the background image from the actual image will significantly reduce dark-charge effects.

2. The baseline can be adjusted by using the F and S Zero pots located on the rear panel of the controller. If these pots are not present, the baseline may be software-adjustable.

3. Offset and excess noise problems are more likely to occur if the controller and camera weren't calibrated and tested as a system at the factory.

Caution

If you observe a sudden change in the baseline signal you may have excessive humidity in the vacuum enclosure of the camera. Turn off the controller (if LN-cooled, remove the liquid nitrogen, also) and have the camera repumped before resuming normal operation. *Contact the factory Customer Support Dept. for information on how to refresh the vacuum. See page 114 for contact information.*

Output Amplifier Selection

Some camera systems are available with dual output amplifiers. If your system has dual output amplifiers, you can choose the array output amplifier (High Capacity or Low Noise) via the WinView/32 on the **Acquisition|Experiment Setup…|Main** tab page. The High Capacity amplifier selection provides a well capacity that is approximately 3 times the well capacity for the Low Noise amplifier selection. High Capacity is suitable when you have intense light signals or signals with high dynamic range. The Low Noise amplifier provides superior signal-to-noise performance and is suitable when you have weak signals.

Note: The choice of output amplifier and analog gain setting should be considered together for the best signal capture.

Analog Gain Control

Analog gain control is used to change the number of electrons required to generate an Analog-to-Digital Unit (ADU, also known as a count). In WinView/32, the analog gain choices are **Low**, **Medium**, and **High**. Users who measure high-level signals may wish to select **Low** to allow digitization of larger signals. At **Medium** gain, the camera has typically been calibrated so the overall noise is ~1 ADU RMS. This setting is suitable for experiments within the mid-level intensity range. Users who consistently measure low-level signals may wish to select **High**, which requires fewer electrons to generate an ADU and reduces some sources of noise. This is a particularly important consideration in absorbance measurements.

Example: The following descriptions assume that the actual incoming light level is identical in all three instances. The numbers used demonstrate the effect of changing a gain setting and do not reflect actual camera performance.

   Low requires eight electrons to generate one ADU. Strong signals can be acquired without flooding the CCD array. If the gain is set to **Low** and the spectra or images appear weak, you may want to change the gain setting to **Medium** or **High**.

   Medium requires four electrons to generate one ADU. If the gain is set to **Medium** and the spectra or images do not appear to take up the fully dynamic range of the CCD array, you may want to change the gain setting to **High**. If the CCD array appears to be flooded with light, you may want to change the setting to **Low**.

   High requires two electrons to generate one ADU and some noise sources are reduced. Because fewer electrons are needed to generate an ADU, weaker signals can be more readily detected. Lower noise further enhances the ability to acquire weak signals. If the CCD array appears to be flooded with light, you may want to change the setting to **Medium** or **Low**.

Analog gain is software-selectable for many of the Princeton Instrument cameras. In WinView/32, gain selection is made on the **Acquisition| Experiment Setup…|ADC** tab card. If there is no Analog Gain parameter on that tab card, analog gain may not be selectable or it may be controlled by a gain switch on the camera, as is the case with older TE- and LN-cooled cameras (see Figure 27).

Note: When software-selection of Analog Gain is available, this selection will override any hardware setting that may be selected at the camera.
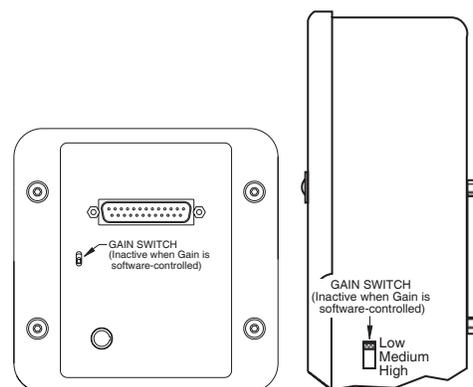

Figure 27. Analog Gain Switch on TE- and LN-cooled Cameras

ST-133 Controller Manual

Readout of the Array

In this section, a simple 6 × 4 pixel CCD is used to demonstrate how charge is shifted and digitized. As described below, two different types of readout are available. Full frame readout, for full frame CCDs, reads out the entire CCD surface at the same time. Frame transfer operation assumes half of the CCD is for data collection and half of the array is a temporary storage area.

Full Frame Readout

The upper left drawing in Figure 28 represents a CCD after exposure but before the beginning of readout. The capital letters represent different amounts of charge, including both signal and dark charge. This section explains readout at full resolution, where every pixel is digitized separately.

Readout of the CCD begins with the simultaneous shifting of all pixels one column toward the "shift register," in this case the column on the far right. The shift register is a single line of pixels along one side of the CCD, not sensitive to light and used for readout only. Typically the shift register pixels hold twice as much charge as the pixels in the imaging area of the CCD.

Readout of the CCD begins with the simultaneous shifting of all pixels one row toward the "shift register," in this case the row on the top. The shift register is a single line of pixels along the top of the CCD, not sensitive to light and used for readout only. Typically the shift register pixels hold twice as much charge as the pixels in the imaging area of the CCD.
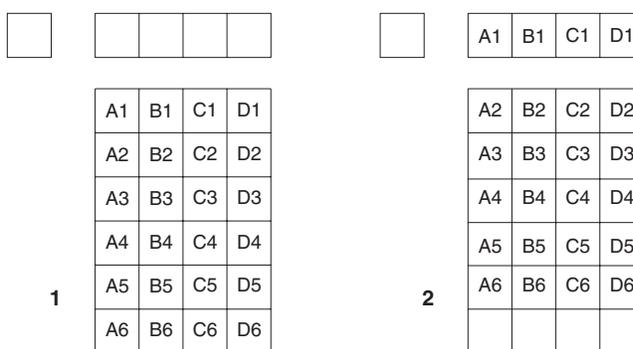
After the first row is moved into the shift register, the charge now in the shift register is shifted toward the output node, located at one end of the shift register. As each value is "emptied" into this node it is digitized. Only after all pixels in the first row are digitized is the second row moved into the shift register. The order of shifting in our example is therefore A1, B1, C1, D1, A2, B2, C2, D2, A3....
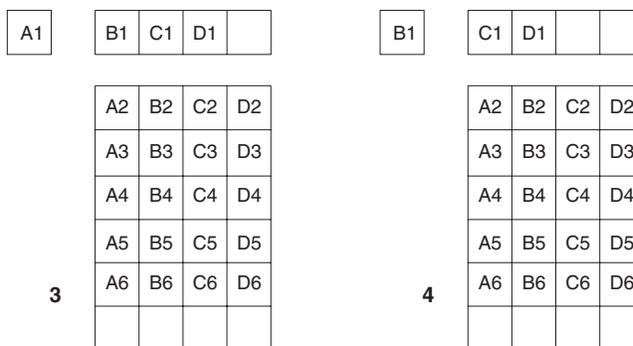
Figure 28. Full Frame at Full Resolution

After charge is shifted out of each pixel the remaining charge is zero, meaning that the array is immediately ready for the next exposure.

Below are the equations that determine the rate at which the CCD is read out. Tables of values for CCDs supported at the time of the printing of this manual also appear below.

The time needed to take a full frame at full resolution is:

$$t_R + t_{exp} + t_c \tag{1}$$

where

> t_R is the CCD readout time,
>
> t_{exp} is the exposure time, and
>
> t_c is the shutter compensation time.

The readout time is approximately given by:

$$t_R = [N_x \cdot N_y \cdot (t_{sr} + t_v)] + (N_x \cdot t_i) \tag{2}$$

where

> N_x is the smaller dimension of the CCD
>
> N_y is the larger dimension of the CCD
>
> t_{sr} is the time needed to shift one pixel out of the shift register
>
> t_v is the time needed to digitize a pixel
>
> t_i is the time needed to shift one line into the shift register
>
> t_s is the time needed to discard a pixel

The readout times for a number of different CCD arrays are provided in Table 4 below.

CCD Array	1 MHz Readout Time (t_R)
EEV CCD-37 512 x 512	0.28 sec.
Kodak KAF-0400 768 x 512	0.5 sec.
Kodak KAF-1400 1317 x 1035	1.5 sec.

Table 4. Approximate Readout Time of a Single Frame for Some CCD Arrays

A subsection of the CCD can be read out at full resolution, sometimes dramatically increasing the readout rate while retaining the highest resolution in the region of interest (ROI). To approximate the readout rate of an ROI, in Equation 2 substitute the x and y dimensions of the ROI in place of the dimensions of the full CCD. Some overhead time, however, is required to read out and discard the unwanted pixels.

Image Readout with Binning
Binning is the process of adding the data from adjacent pixels together to form a single pixel (sometimes called a super-pixel), and it can be accomplished in either hardware or software. Rectangular groups of pixels of any size may be binned together, subject to some hardware and software limitations.

Hardware binning is performed *before* the signal is read out by the preamplifier. For signal levels that are readout noise limited this method improves S/N ratio linearly with the number of pixels grouped together. For signals large enough to render the camera

photon shot noise limited, the S/N ratio improvement is roughly proportional to the square-root of the number of pixels binned.

Figure 29 shows an example of 2×2 binning. Each pixel of the image displayed by the software represents 4 pixels of the CCD array. Rectangular bins of any size are possible.

Binning also reduces readout time and the burden on computer memory, but at the expense of resolution. Since shift register pixels typically hold only twice as much charge as image pixels, the binning of large sections may result in saturation and "blooming", or spilling of charge back into the image area.
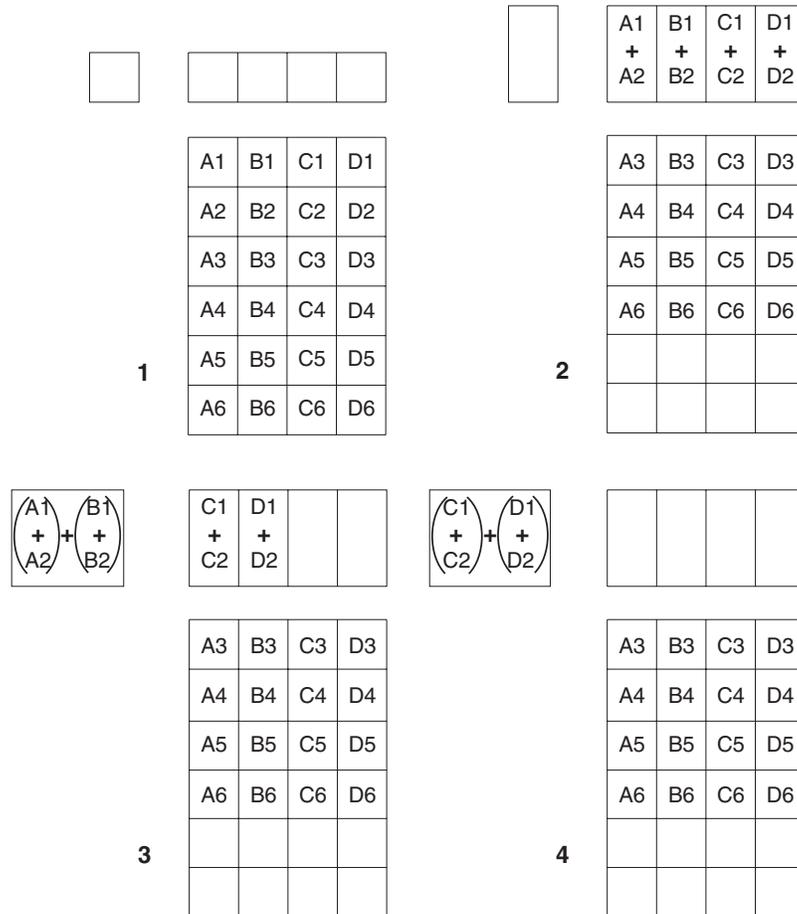

Figure 29. 2×2 Binning for Images

The readout rate for $n \times n$ binning is approximated using a more general version of the full resolution equation. The modified equation is:

$$t_R = \left[N_x \cdot N_y \cdot \left(\frac{t_{sr}}{n} + \frac{t_v}{n^2} \right) \right] + \left(N_x \cdot t_i \right) \qquad (3)$$

Binning in Software

One limitation of hardware binning is that the shift register pixels and the output node are typically only 2-3 times the size of imaging pixels as shown in Table 5. Consequently, if the total charge binned together exceeds the capacity of the shift register or output node, the data will be lost.

CCD Array	Imaging Section Well Capacity	Horizontal Shift Register Well Capacity	Preamp Node Well Capacity
EEV 512 x 512	100×10^3 electrons	200×10^3 electrons	400×10^3 electrons
Kodak 768 x 512	85×10^3 electrons	170×10^3 electrons	340×10^3 electrons
Kodak 1317 x 1035	45×10^3 electrons	90×10^3 electrons	180×10^3 electrons

Table 5. Well Capacity for Some CCD Arrays

This restriction strongly limits the number of pixels that may be binned in cases where there is a small signal superimposed on a large background, such as signals with a large fluorescence. Ideally, one would like to bin many pixels to increase the S/N ratio of the weak peaks but this cannot be done because the fluorescence would quickly saturate the CCD.

The solution is to perform the binning in software. Limited hardware binning may be used when reading out the CCD. Additional binning is accomplished in software, producing a result that represents many more photons than was possible using hardware binning.

Software averaging can improve the S/N ratio by as much as the square-root of the number of scans. Unfortunately, with a high number of scans, i.e., above 100, camera 1/f noise may reduce the actual S/N ratio to slightly below this theoretical value. Also, if the light source used is photon-flicker limited rather than photon shot-noise limited, this theoretical signal improvement cannot be fully realized. Again, background subtraction from the raw data is necessary.

This technique is also useful in high light level experiments, where the camera is again photon shot-noise limited. Summing multiple pixels in software corresponds to collecting more photons, and results in a better S/N ratio in the measurement.

Frame Transfer Readout

The ST-133 fully supports frame transfer readout. Operation in this mode is very similar to the operation of video rate cameras. Half of the CCD is exposed continuously, raising the exposure duty cycle to nearly 100%. The other half of the CCD is masked to prevent exposure, and it is here that the image is "stored" until it can be read out.

Figure 30 shows the readout of a masked version of our sample 4×6 CCD. The shading represents the masked area (masking is on the array).

1 Charge accumulates in unmasked cells during exposure.

2 Accumulated charge in exposed cells is quickly transferred under mask.

3 Charge from cells A1-D1 shifted to serial register. Exposed cells accumulate new charge.

4 Charges in serial register shift into Output Node, emptying the register so the next line can be transferred in.

5 Shifting continues until all masked data has been shifted into serial register and from there to the Output Node.

6 All data from first exposure has been shifted out. Second exposure continues. Initial conditions are restored.

Figure 30. Frame Transfer Readout

Only the exposed region collects charge. At the end of the exposure, the charge is quickly shifted into the masked region. Since the shifting is accomplished in a short time, i.e., a few milliseconds, the incident light causes only minimal "smearing" of the signal. While the exposed region continues collecting data, the masked region is read out and digitized. The percentage of smearing given by the equation below is simply the time needed to shift all rows from the imaging area divided by the exposure time.

$$\frac{N_x t_i}{t_{exp}} \tag{4}$$

Digitization

During readout, an analog signal representing the charge of each pixel (or binned group of pixels) is digitized. The number of bits per pixel is based on both the hardware and the settings programmed into the camera through the software. One A/D converter (one digitization speed) is standard with the ST-133. However, the ST-133 will support multiple digitization speeds (software-selectable readout rates) if the Dual A/D Converters option is ordered or if a 2 MHz version of the ST-133 is ordered for the system.

Multiple digitization provides optimum signal-to-noise ratios at all readout speeds. Because the readout noise of CCD arrays increases with the readout rate, it is sometimes necessary to trade off readout speed for high dynamic range. In the most common ST-133 configurations, there will be a 1 MHz conversion speed for the fastest possible data collection and a 100 kHz or 50 kHz conversion speed for use where noise performance is the paramount concern. Switching between the conversion speeds is completely under software control for total experiment automation.

Specifications

CCD Arrays

Spectral Range
400-1080 nm; 190-1080 nm with UV-to-visible coating on the CCD

Types
The ST-133 can be operated with many different Princeton Instruments cameras, each of which is available with a variety of different CCD chips as specified at the time of order. Contact the factory for up-to-date information on the performance characteristics of the array installed in your particular camera.

Temperature Control

Setting Mechanism: Temperature is set by the application software.

Display: The actual temperature can be displayed at the computer by the application software.

Stability: ±0.050°C over entire temperature range

Temperature Range: A function of camera type; see manual for your particular camera.

Time to Lock: A function of camera type; see manual for your particular camera.

Inputs

Note: See *Appendix B, PTG Module*, for information about the PTG connectors.

EXT SYNC: TTL input (BNC) to allow data acquisition to be synchronized with external events. Sense can be positive or negative going as set in software. Synchronization and Trigger Modes are discussed in Chapter 5.

Outputs

VIDEO: 1 V pk-pk from 75 Ω, BNC connector. Either RS-170 (EIA) or CCIR standard video as specified when system was ordered. Requires connection via 75 Ω cable that must be terminated into 75 Ω.

$\overline{\text{SCAN}}$**:** TTL output (BNC) for monitoring camera status. *Logic output is software-selectable as either NOTSCAN or SHUTTER.* When the logic output is NOTSCAN, it is at a TTL low when CCD is being read; otherwise high. When the logic output is SHUTTER, the output precisely brackets shutter-open time (exclusive of shutter compensation) and can be used to control an external shutter or to inhibit a pulser or timing generator. Default selection is SHUTTER.

$\overline{\text{READY}}$**:** TTL output (BNC); marks start of *first* exposure. When run is initiated, remains high until completion of cleaning cycles preceding *first* exposure, then goes low and remains low for duration of run.

Input/Outputs

SERIAL COM: (TAXI) Data link to computer via proprietary cable connected to this 9-pin "D" connector. Cable lengths to 165 feet (50 m) available.

USB 2.0: (USB 2.0) Data link to computer via 5 meter USB cable connected to this connector.

A/D Converters

The ST-133 is available in a number of different configurations. The configuration provided for a specific order is determined primarily by the choice of camera specified at the time of purchase. With some configurations it is possible to have two A/D converters installed. With others there can only be one. Both 12- and 16-bit converters are available at speeds as high as 1 MHz. Not all converters are available for all cameras. Some converters run at one speed only. Others can operate at more than one speed as selected in software. Low-speed operation gives better noise performance; high-speed operation allows faster data acquisition.

Readout Rate: A function of the installed converter. Speeds as high as 1 MHz (12- and 16-bits) and as low as 50 kHz are currently available.

Linearity: better than 1%.

Readout noise: 1-1.2 counts RMS on standard controllers.

Exposure (Integration) Time

5 msec to 2.3 hours (full frame or frame transfer).

Shutter Compensation Time

The following numbers apply for a 1 MHz ST-133.

Shutter	Exposure
Vincent (small)	8.0 msec
Prontor 40 (large)	28.0 msec
Prontor 23 (external)	8.0 msec
Intensified (electronic)	6.0 msec
NONE	200 nsec

Computer Requirements

Depending on the communication protocol (TAXI or USB 2.0) the ST-133 is most commonly used with a Pentium computer configured as follows.

Type:

TAXI: 200 MHz Pentium® II (or better)

USB 2.0: 1 GHz Pentium 3 (or better)

Memory (RAM):

TAXI: Minimum of 32 Mbytes; possibly more depending on experiment design and size of CCD Array.

USB 2.0: Minimum of 256 Mb of RAM.

Operating System:

TAXI: Windows 95®, Windows NT® or later for WinView/32 and WinSpec/32.

USB 2.0: Windows 2000 (with Service Pack 3), Windows XP (with Service Pack 1) or later operating system.

Interface:

TAXI: PCI High-Speed Serial I/O card

USB 2.0: USB Interface Card (Orange Micro 70USB90011 USB2.0 PCI is recommended)

Miscellaneous

Dimensions: See Appendix E.

Controller Weight: 5.45 kg.

Power Requirements: Nominally 100, 120, 220 or 240 V AC, 47-63 Hz, 300 watts; required DC voltages are generated in the controller. Power to camera is applied via controller cable.

Environmental Requirements:

Storage temperature: -20° C to 55° C;

Operating temperature range over which specifications can be met: 18° C to 23° C;

Relative humidity: ≤50% noncondensing.

TTL Requirements: Rise time ≤ 40 nsec, Duration ≥ 100 nsec.

PTG Module

Description

The Princeton Instruments Programmable Timing Generator (PTG) is a plug-in module designed for operation in the ST-133 Controller. Incorporating the Timing Generator into the Controller in this manner allows pulsed operation of the PI-MAX camera in pulsed measurements without the inconvenience and expense of a separate timing generator. The novel and highly integrated design of the PTG, with its advanced high-speed electronics, low insertion delay and wide range of programmable functions, achieves superior performance as the ultimate gate controller for the PI-MAX camera.

Note: The combination of PTG and the USB 2.0 interface is supported by versions 2.5.15 and higher of WinView/32 and WinSpec/32.
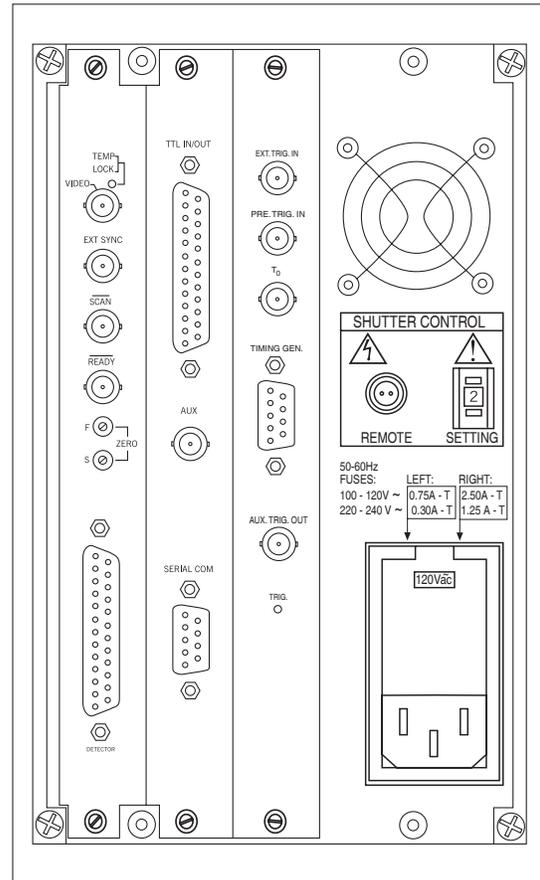
Figure 31. ST-133 with Programmable Timing Generator and PCI (TAXI) Interface Control Module

Specifications

Back panel I/O

Pre-Trigger Input: BNC (10 kΩ impedance), TTL level used only to start a bracket pulse.

External Trigger Input: BNC, fully configurable trigger input (see Trigger specifications below).

T0 Output (Selected Trigger Output): BNC, TTL level, output of trigger selector. If burst pulsing is turned Off, the **T0 Output** is asserted after either an External or an Internal trigger and a pulse ensemble is then produced. The **T0 Output** is deasserted when a pulse ensemble is completed. *A pulse ensemble consists of a Gate Start pulse, a Gate Stop pulse and an Auxiliary pulse.*

If burst pulsing is turned On, the **T0 Output** is deasserted when the last pulse ensemble is completed.

Auxiliary Trigger Output: BNC, AC-coupled pulse output. The auxiliary timer's output is available to the user through a rear panel BNC for triggering other system components. The host software sets the Delay Time of the auxiliary trigger output with respect to the PTG trigger time.

Figure 32. Auxiliary Trigger Output

Figure 32 is an oscilloscope screen capture of the Auxiliary Trigger output. For proper timing, users should trigger on the leading edge of the output waveform (point 1 as indicated in Figure 32 and not at point 2, 3, or 4).Use positive-edge triggering and a positive trigger level from +1.0 to +1.5 V. If using it to drive logic, we suggest that the 74HCT or 74ACT logic-device families be used.

Timing Gen Interface: DB9 connector carrying the **Start**, **Stop** and **Bracket Pulse** signals. These signals are connected to the head to control the photocathode and MCP gating and are not directly available.

Gate Start pulse: switches photocathode On.

Gate Stop pulse: switches photocathode Off.

Bracket Pulse: In bracket pulsing **On** operation, biases MCP On; timing controlled by software; asserted before Gate Start[*] and deasserted after Gate Stop.

Operating modes
Continuous: Pulse Width and Pulse Delay remain constant over the course of the measurement for all triggers.

Sequential: Pulse Width, Pulse Delay, or both change as the measurement progresses.

Fixed: Incremental change in Pulse Width and/or Pulse Delay is constant for each trigger.

Exponential: Incremental change in Pulse Width and/or Pulse Delay varies with each trigger; well suited to fluorescence decay experiments.

Anticipated Trigger: Allows bracket pulsing operation with repetitive trigger source having a fixed period. Hardware determines trigger period and starts bracket pulse at specified interval prior to trigger.

Trigger
Modes:

Internal: PTG generates triggers at the specified frequency; each trigger initiates a pulse ensemble that is applied to PI-MAX.

---

[*] Value differs for each head (500 ns to 700 ns typical) and is stored in NVRAM.

External: Each trigger applied to Ext. Trig. In BNC initiates a pulse ensemble that is applied to PI-MAX.

Readout Cycle: Readout cycle is triggered through the ST-133 backplane if **Int. Sync.** is selected on Experiment Setup **Timing** tab page.

Enabling: Handshakes that prevent a readout from occurring while the PTG is busy and that prevent the PTG from pulsing the photocathode ON while a readout cycle is in progress are performed through the backplane.

External Trigger:

    Levels: -6 V to + 6 V DC

    External Level Resolution: 48 mV

    Slope: selectable.

    Coupling: AC and DC selectable.

    Input Hysteresis: 100 mV

    Repetition Rate: up to 1 MHz

    Bandwidth: 700 MHz

Internal Trigger:

    Repetition rate:

        minimum: 0.1 Hz

        maximum: 1 MHz

        resolution: 12.5 ns

Timing

Trigger gate start delay:

    minimum: 24 ns

    maximum: 20 ms[*]

    resolution: 0.04 ns

Gate Pulse width:

    minimum: 0.0 ns

    maximum: 20 ms[*]

    resolution: 0.04 ns

Trigger to Auxiliary delay:

    minimum: 24 ns

    maximum: 10 ms

    resolution: 0.04 ns

---

[*]   start delay + gate width = 20 ms maximum

Operation

Introduction

Operation of the PTG module is quite simple. Most of the functions are performed automatically through the backplane and the parameters are set via the Pulser Setup screens of the host software (WinView/32 or WinSpec/32, version 2.4 and higher). Operated in the External Trigger mode, a trigger is applied to the **Ext. Trig. In** connector. No other connections to the PTG's BNC connectors are required. When operated in the Internal Trigger mode, unless a PTG output is used to trigger a peripheral system component, no connections to the BNC connectors would be required at all. Figure 33 illustrates the connections in a typical system.
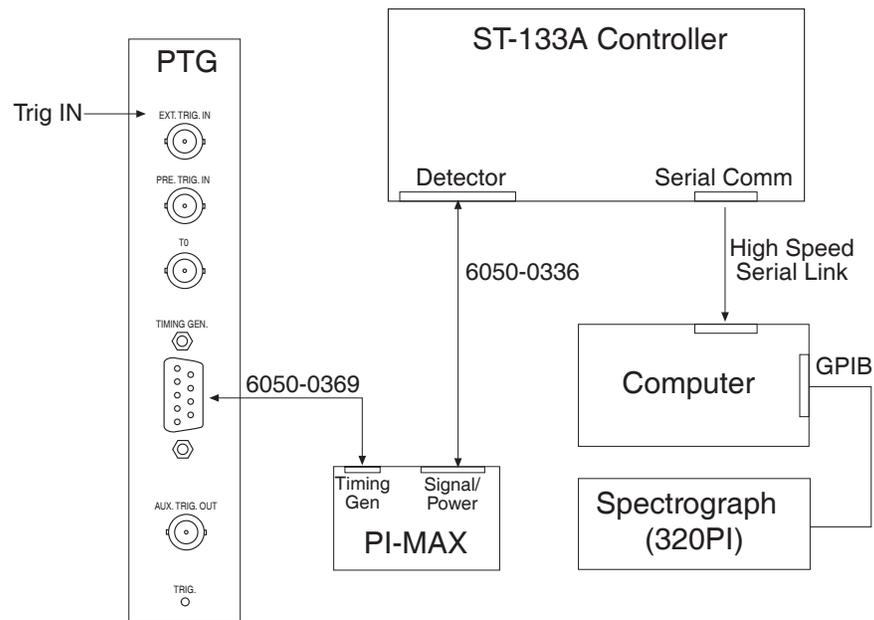
Figure 33. Typical System Cabling

Handshakes

There are two possible conflicts that need to be avoided when pulsing an intensifier.

- To prevent artifacts from the laser from affecting the data, a readout should not be initiated while the PTG is busy.

- Triggering the timing generator should be inhibited while a readout is in progress to prevent high-voltage pulses from causing artifacts in the data.

The handshakes to accomplish these enabling/inhibiting operations take place automatically, the necessary signals being exchanged via the backplane. No extra cabling or operator intervention is required.

Internal Synchronization

It is necessary to initiate a readout after each exposure. In a system having a PTG, this is accomplished automatically by operating the PTG in the Internal Sync mode. This mode is established by making the following Experiment Setup selections:

1. Experiment Setup **Main** tab page: Set the **Exposure Time** to 0.

2. Experiment Setup **Timing** tab page: Select **Internal Sync** Timing Mode, deselect the **Continuous Cleans** check box, select **Disabled Opened** for the Shutter Control, and select the **PreOpen** check box.

It is *not* necessary to connect a signal to the ST-133's **Ext Sync** BNC connector.

Notes:

1. Internal Sync only appears as a selection if PTG has been selected as the active timing generator via the Pulsers dialog box, which opens when Pulsers is selected on the host software Setup menu.

2. Users also have the option of selecting either the Free Run or External Sync Timing mode. In the Ext Sync mode, each readout is initiated by applying an appropriately timed TTL edge to the ST-133's Ext Sync BNC connector. You can select either the positive-going or negative-going edge via the Trigger Edge parameter, which is also located on the Experiment Setup **Timing** tab page of the host software.

Software

Both WinView/32 and WinSpec/32 support the PTG. In both programs, pulser support must be selected when the software is installed, as discussed in the *Installation* chapter of the software manual.

Procedure

Basic PTG operation is reviewed in the following paragraphs. The individual dialog box and tab page selections are discussed in detail in the PTG manual.

1. Following the intensifier precautions stated in the hardware manuals, turn on the Controller (PTG installed). *If the Controller isn't turned on, the software won't be able to control the PTG.*

2. Select the WinView/32 or WinSpec/32 icon.

Note: The gate functions of the PI-MAX camera are controlled by the PTG. If the system is equipped with a PI-MAX camera, the Camera State dialog box (Figure 34) **will appear after the controller has been turned on and the software is started**. Although the software always initially places the PI-MAX in Safe mode, the user has the option of restarting with the last settings or reverting to the factory defaults, which are:

Figure 34. Camera State Dialog Box

    Mode: Safe
    Exposure Time: 10 ms
   **Intensifier Gain:** precisely midrange (128 on arbitrary 1 to 256 Intensifier Gain scale).

3. On the **Setup** menu select **Pulsers** to open the Pulsers dialog box.

4. Select **PTG**. Then click on the **Setup Pulser** button. The PTG dialog box (Figure 36) will open. *If PTG is grayed out on the* **Pulsers** *dialog box, PTG support has not been installed.*


Figure 35. Pulsers Dialog Box
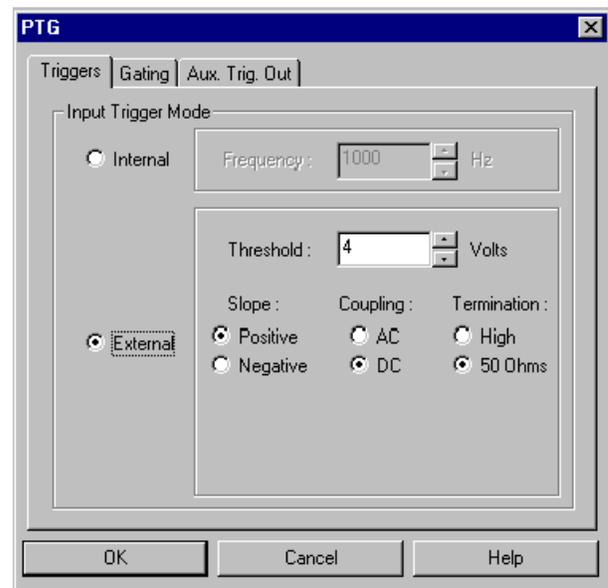
Figure 36. PTG Dialog Box

Triggers and Gating Setup

The remainder of the setup information is detailed in the PTG manual. Please refer to that document when selecting trigger and gating modes and setting their respective timing parameters.

Experiments

The kinds of experiments that can be performed with a PI-MAX camera and PTG are shown in Figure 37. Of the many gated measurements that can be performed with a PI-MAX and PTG, most will fall into one of the following categories:

- **Static Gate:** This type of experiment may also be referred to as "Repetitive-Continuous". There is a repetitive trigger, and the Gate Width and Gate Delay are fixed. Some variable in the experiment such as pressure, concentration, wavelength or temperature is varied.

- **Swept Gate:** In this type of experiment, Gate Width, Gate Delay, or both may be varied.

  Repetitive-Sequential 1: The Trigger is repetitive, Gate Width is fixed, and Delay is varied over the course of the measurement. The result of the experiment is a plot of intensity vs. time, such as might be obtained with a sampling oscilloscope. This technique is used to measure lifetime decays.

  Repetitive-Sequential 2: The Trigger is repetitive and Gate Width and Delay are varied over the course of the measurement. Gate Width and Delay can be incremented in a linear fashion or in an exponential fashion. Increasing the Gate Width is useful for trying to find fine detail in a weak decaying signal. If you choose linear, you have to take a lot more points. Exponential lets you take data points closer together where the signal is changing rapidly and further apart where the signal is changing slowly.

- **Single Shot:** A single shot experiment is one where you've only got one chance to catch the data. Any experiment that can't be repeated more often than once a minute, such as high power lasers, and explosives, is considered a single shot. You have to catch the trigger when it comes. Prior to the event, the CCD runs in continuous cleans mode. You don't have the luxury of having the CCD just sitting there doing nothing because the CCD will be accumulating dark current. When the trigger arrives, the intensifier gates, the continuous cleans stop, and the array is read out with a minimum of dark current.
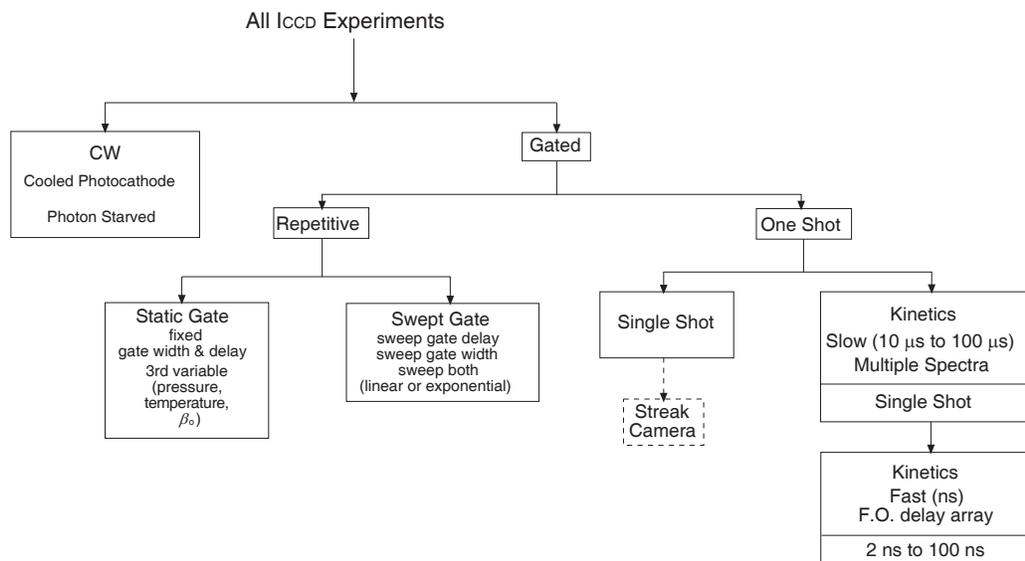
Figure 37. Experiments with the PI-MAX

Please refer to the PTG manual for detailed information on hardware and software setup for these types of experiments.

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TTL Control

> **TTL In/Out control is not currently supported under USB 2.0.**

Introduction

This connector provides 8 TTL lines in, 8 TTL lines out and an input control line. Figure 38 illustrates the connector and lists the signal/pin assignments.

Princeton Instrument's WinView/32 and WinSpec/32 software packages incorporate WinX32 Automation, a programming language that can be used to automate performing a variety of data acquisition and data processing functions, including use of the TTL IN/OUT functions. WinX32 Automation can be implemented in programs written in Visual Basic. See the WinX32 documentation for more detailed information.

TTL In

The user controls the 8 TTL Input lines, setting them high (+5 V; TTL 1) or low (0 V; TTL 0). When the lines are read, the combination of highs and lows read defines a decimal number which the computer can use to make a decision and initiate actions as specified in the your program. If a TTL IN line is low, its numeric value is 0. If a TTL IN line is high, its numeric value is as follows.

TTL IN	Value	TTL IN	Value
1	1	5	16
2	2	6	32
3	4	7	64
4	8	8	128

This coding allows any decimal value from 0 to 255 to be defined. Thus, as many as 256 different sets of conditions can be specified, at the user's discretion, using the TTL IN lines. *Any unused lines will default to TTL high (+5 V).* For example, to define the number three, the user would simply set the lines TTL IN 1 and TTL IN 2 both high (+5 V). It would be necessary to apply TTL low to the remaining six lines because they would otherwise default to TTL high as well.

TTL IN	Value	TTL IN	Value
1	High (1)	5	Low (0)
2	High (2)	6	Low (0)
3	Low (0)	7	Low (0)
4	Low (0)	8	Low (0)

Table 6 illustrates this coding for decimal values 0 through 7. Obviously this table could easily be extended to show the coding for values all the way to 255.

Decimal Equiv.	TTL IN/OUT 8 1= dec 128	TTL IN/OUT 7 1=dec 64	TTL IN/OUT 6 1=dec 32	TTL IN/OUT 5 1=dec 16	TTL IN/OUT 4 1=dec 8	TTL IN/OUT 3 1=dec 4	TTL IN/OUT 2 1=dec 2	TTL IN/OUT 1 1=dec 1
0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	1	0
3	0	0	0	0	0	0	1	1
4	0	0	0	0	0	1	0	0
5	0	0	0	0	0	1	0	1
6	0	0	0	0	0	1	1	0
7	0	0	0	0	0	1	1	1

Table 6. Bit Values with Decimal Equivalents:
1 = High,
0 = Low

Buffered vs. Latched Inputs

In controlling the TTL IN lines, users also have the choice of two input-line states, *buffered* or *latched*. In the buffered state, the line levels must remain at the intended levels until they are read. With reference to the preceding example, the high level at TTL IN 1 and TTL IN 2 would have to be maintained until the lines are read. In the latched state, the applied levels continue to be available until read, even if they should change at the TTL IN/OUT connector.

This control is accomplished using the EN/CLK TTL input (pin 6). If EN/CLK is open or high, *buffered* operation is established and the levels reported to the macro will be those in effect when the READ is made. With reference to our example, if pin 6 were left unconnected or a TTL high applied, TTL IN 1 and TTL IN 2 would have to be held high until read. If, on the other hand, EN/CLK were made to go low while TTL IN 1 and TTL IN 2 were high, those values would be *latched* for *as long as EN/CLK remained low*. The levels actually present at TTL IN 1 and TTL IN 2 could then change without changing the value that would be read by software.

TTL Out

The state of the TTL OUT lines is set from WinView/32. Typically, a program monitoring the experiment sets one or more of the TTL Outputs. Apparatus external to the ST-133 interrogates the lines and, on detecting the specified logic levels, takes the action appropriate to the detected condition. The coding is the same as for the input lines. There are eight output lines, each of which can be set low (0) or high (1). The combination of states defines a decimal number as previously described for the TTL IN lines.

Pin #	Assignment	Pin #	Assignment
1	IN 1	14	IN 2
2	IN 3	15	IN 4
3	IN 5	16	IN 6
4	IN 7	17	IN 8
5	GND	18	GND
6	EN/CLK	19	Reserved
7	(future use)	20	GND
8	GND	21	OUT 2
9	OUT 1	22	OUT 4
10	OUT 3	23	OUT 6
11	OUT 5	24	OUT 8
12	OUT 7	25	GND
13	Reserved		

Table 7. TTL In/Out Connector Pinout

TTL IN/OUT
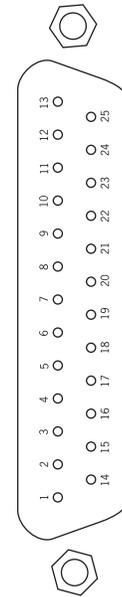
Figure 38. TTL In/Out Connector

TTL Diagnostics Screen

Note that WinView/32 provides a TTL Diagnostics screen (located in WinView/32 under *Hardware Setup - Diagnostics)* that can be used to test and analyze the TTL In/Out lines.

Hardware Interface

A cable will be needed to connect the TTL In/Out connector to the experiment. The design will vary widely according to each user's needs, but a standard 25-pin female type D-subminiature connector will be needed to mate with the TTL In/Out connector at the ST-133. The hardware at the other end of the cable will depend entirely on the user's requirements. If the individual connections are made using coaxial cable for maximum noise immunity (recommended), the center conductor of the coax should connect to the proper signal pin and the cable shield should connect to the nearest available ground (grounds are conveniently provided at pins 5, 8, 18 and 20). Connector hardware and cables of many different types are widely available and can often be obtained locally, such as at a nearby electronics store. A list of possibly useful items follows. Note that, although the items listed may be appropriate in many situations, they might not meet your specific needs.

- 25-pin female type D-subminiature solder type connector (Radio Shack® part no. 276-1548B).

- RG/58U coaxial cable.

- Shielded Metalized hood (Radio Shack part no. 276-1536A).

- BNC connector(s) type UG-88 Male BNC connector (Radio Shack part no. 278-103).

Example

Suppose you needed to build a cable to monitor the line TTL OUT 1. One approach would be to build a cable assembly as described in the following paragraphs. This procedure could easily be adapted to other situations.

1. Begin with a 25-pin female type D-subminiature solder type connector (Radio Shack part no. 276-1548B). This connector has 25 solder points open on the back.

2. Referring to Table 7, note that pin 8 = GND and pin 9 = TTL OUT 1.

3. Using coaxial cable type RG/58U (6 feet length), strip out the end and solder the outer sheath to pin 8 (GND) and the inner line to pin 9 (TTL OUT 1). Then apply shielding to the lines to insulate them.

4. Mount the connector in a Shielded Metalized hood (Radio Shack part no. 276-1536A).

5. Build up the cable (you can use electrical tape) to where the strain relief clamp holds.

6. Connect a BNC connector (UG-88 Male BNC connector) to the free end of the cable following the instructions supplied by Radio Shack on the box (Radio Shack part no. 278-103).

7. To use this cable, connect the DB25 to the TTL IN/OUT connector on the back of the ST-133 controller.

8. To check the cable, start WinView/32 and open the TTL Diagnostics screen (located in WinView under *Hardware Setup - Diagnostics*). Click the **Write** radio button. Then click the **Output Line 1** box. Next click the **OK** button to actually set TTL OUT 1 high. Once you set the voltage, it stays until you send a new command.

9. Measure the voltage at the BNC connector with a standard voltmeter (red on the central pin, black on the surrounding shielding). Before clicking **OK** at the TTL Diagnostics screen you should read 0 V. After clicking **OK** you should read +5 V.

Note that adding a second length of coaxial cable and another BNC connector would be straightforward. However, as you increase the number of lines to be monitored, it becomes more convenient to consider using a multiple conductor shielded cable rather than individual coaxial cables.

Appendix D

Cleaning and Maintenance

WARNING | Turn off all power to the equipment and secure all covers before cleaning the units. Otherwise, damage to the equipment or injury to yourself could occur.

Cleaning

Controller and Camera

Although there is no periodic maintenance that *must* be performed on the ST-133 Controller or on the Camera, users are advised to clean these components from time to time by wiping them down with a clean damp cloth. This operation should only be done on the external surfaces and with all covers secured. In dampening the cloth, use clean water only. No soap, solvents or abrasives should be used. Not only are they not required, but they could damage the finish of the surfaces on which they are used.

Optical Surfaces

Optical surfaces may need to be cleaned due to the accumulation of atmospheric dust. We advise that the *drag-wipe* technique be used. This involves dragging a clean cellulose lens tissue dampened with clean anhydrous methanol over the optical surface to be cleaned. Do not allow any other material to touch the optical surfaces.

Changing the ST-133 Line Voltage and Fuses

The appropriate voltage setting for your country is set at the factory and can be seen on the back of the power module. If your voltage source changes, you will need to change the voltage setting and you may need to change the fuse configuration.

WARNING! Use proper fuse values and types for the controller and detector to be properly protected.

To Change Voltage and Fuse Configuration:

WARNING! Before opening the power module, turn the Controller OFF and unplug the powercord.

1. As shown in Figure 39, place the flat side of a flat bladed screwdriver parallel to the back of the Controller and behind the small tab at the top of the power module, and twist the screwdriver slowly but firmly to pop the module open.

2. To change the voltage setting, roll the selector drum until the setting that is closest to the actual line voltage is facing outwards.

3. Confirm the fuse ratings by removing the two white fuse holders. To do so, simply insert the flat blade of the screwdriver behind the front tab of each fuse holder and gently pry the assembly out.
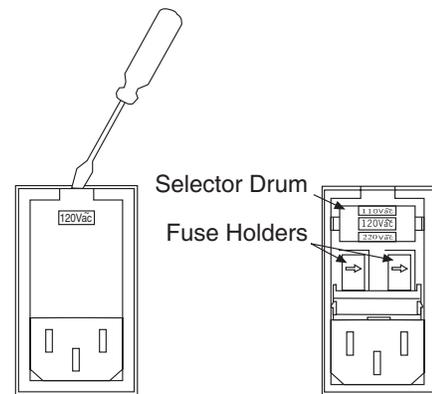
Figure 39. Power Input Module
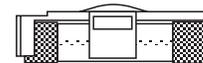
Figure 40. Fuse Holder

4. Refer to the Fuse/Voltage label (above or below the Power Module) to see which fuses are required by the selected voltage. If Controller power switch is on the back of the ST-133, the Fuse/Voltage label is located below the Power Module.

5. After inspecting and if necessary, changing the fuses to those required by the selected voltage, reinstall the holders with the arrow facing to the right.

6. Close the power module and verify that the correct voltage setting is displayed.

7. Verify that the Controller power switch is in the OFF position and then plug the powercord back into the power module.

Appendix E

Outline Drawings of
ST-133 Controller

Note: *Dimensions are in inches and mm.*
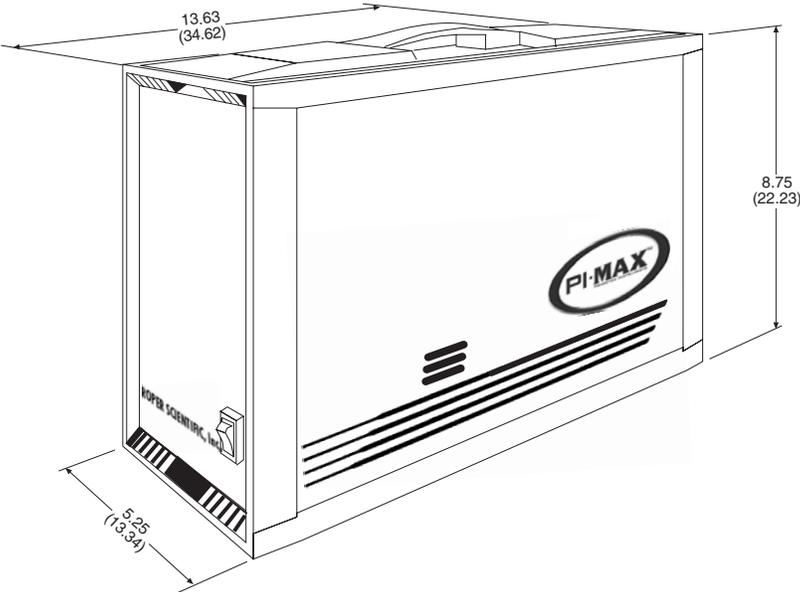
Figure 41. ST-133A Controller Dimensions
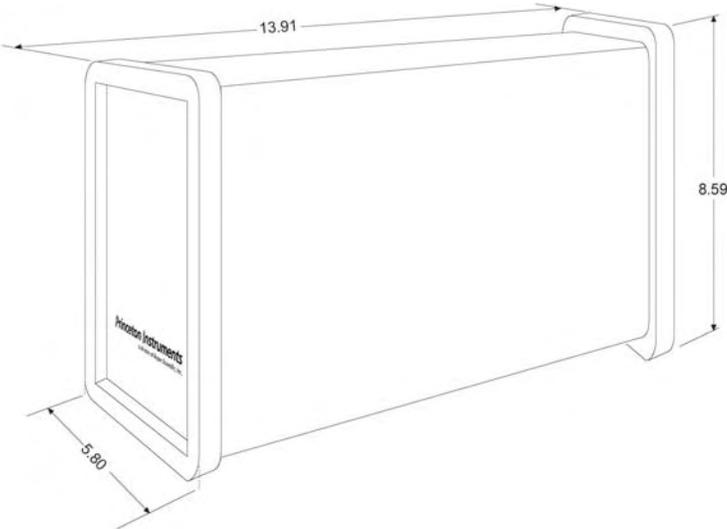
Figure 42. ST-133B Controller Dimensions

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Appendix F
Plug-In Modules

Introduction

The ST-133 Controller has three plug-in slots. The Analog/Control module (leftmost slot when the controller is viewed from the rear) and the Interface Control module (either a TAXI or a USB 2.0 compatible module in the middle slot) are always provided. The third slot is covered with a blank panel unless a PTG module has been installed.

If a module is ever removed for any reason, internal settings should *not* be disturbed. Changing a setting could radically alter the controller's performance. Restoring normal operation again without proper equipment and guidance would be very difficult, and it might be necessary to return the unit to the factory for recalibration.

WARNING
> Modules should *never* be removed or installed when the controller is under power. If a module is removed or installed when the controller is powered, permanent equipment damage could occur which would not be covered by the warranty.

Removing/Installing a Plug-In Module

WARNINGS!
> 1. Always turn the Controller OFF before removing or installing a module. If a module is removed or installed when the controller is powered, permanent equipment damage could occur which would not be covered by the warranty.
>
> 2. Before handling any boards, take precautions to prevent electrostatic discharge (ESD). The modules are susceptible to ESD damage. Damage caused by improper handling is not covered by the Warranty.

To Remove a Module:

1. Verify that the Controller has been turned OFF.

2. Rotate the two locking screws (one at the top of the module and one at the bottom) counterclockwise until they release from the chassis.

3. Then, grasp the module and pull it straight out.

4. Set the module aside in a safe place. If you are replacing it with another module, as in the case of exchanging a TAXI module with a USB 2.0 module, you may be able to use the packaging from the new module to store the module being replaced. This packaging is usually an antistatic bag that will protect the module components from electrostatic discharge.
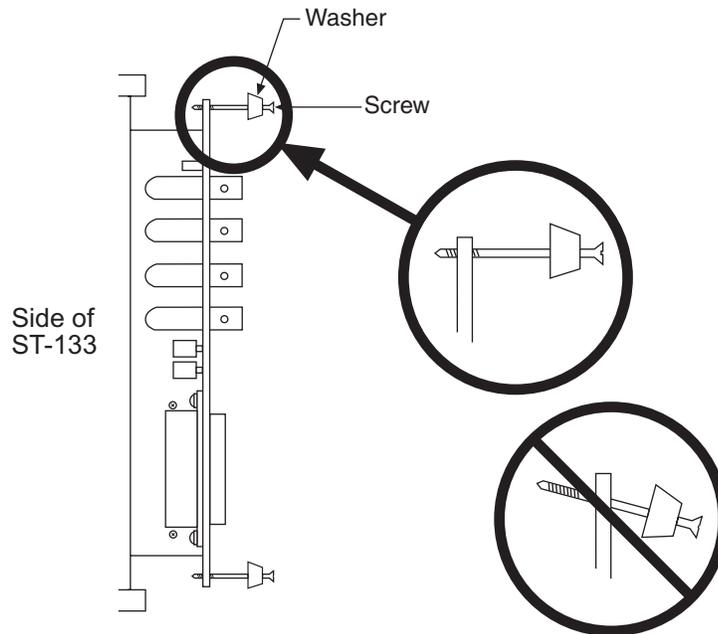
Figure 43. Module Installation

To Install a Module:

Installing a module is a bit more complex because you first have to be sure the locking screws are aligned correctly. The following procedure is suggested.

1. Verify that the Controller has been turned OFF.

2. Remove the replacement module from its antistatic packaging. This packaging is designed to protect the module components from electrostatic discharge.

3. Rotate the two locking screws counterclockwise until the threads on the screws engage those of the module panel. *See Figure 43.* By doing this, the screws will be perfectly perpendicular to the module panel and will align perfectly when the module is inserted.

4. Insert the module so that the top and bottom edges of the board are riding in the proper guides.

5. Gently but firmly push the module in until the 64-pin DIN connector at the back of the module mates with the corresponding connector on the backplane, leaving the module panel resting against the controller back panel.

6. Rotate the two locking screws clockwise. As the screws are rotated, they will first disengage from the module panel threads, and then begin to engage those of the bracket behind the controller panel.

WARNING! Tighten the screws to where they are just snug. Do *not* tighten them any further because you could easily bend the mating bracket.

Appendix G

Interline CCD Cameras

Introduction

This appendix discusses the operation and theory of a Princeton Instruments camera with an interline CCD. Operationally, a camera with a conventional CCD and one having an interline CCD are quite similar, the principal difference being that a shutter would ordinarily not be required if the camera has an interline chip.

The function of the camera is to collect very low intensity light and convert the energy into a quantitative, electronic signal (photo-electrons) over a two-dimensional space. To do this, light from the subject is focused onto an interline CCD array, in which imaging and light-insensitive readout registers alternate and where the specified number of columns of pixels for the chip is, in fact, the number of register pairs. Because the charge on each image pixel never has to transfer more than one row, the transfer can be made very quickly without smearing.

It is important to note that an interline chip can operate in either of two timing modes, overlapped or non-overlapped. The operating mode is always overlapped unless the exposure time is shorter than the readout time, in which case non-overlapped operation is automatically selected by the controlling software. Because overlapped operation is faster, it is generally preferable to operate in the overlapped mode for the fastest possible data acquisition.

In some situations, ***increasing the exposure time*** slightly will cause the camera to switch from non-overlapped to overlapped operation. When this happens, the video may blank for a moment as the unit is reprogrammed, and then reappear with approximately double the frame rate that was available when it was operating non-overlapped. Detailed discussions of how the interline camera works and the implications for operation follow.

Available interline CCD formats include the Sony ICX061 1300×1030. A special clocking mode to minimize background signal is supported. *Contact Roper Scientific for more information.*

Overlapped vs. Non-Overlapped Operation

There are two basic operating modes, overlapped and non-overlapped. Operated in the overlapped mode, at the end of the exposure time, readout begins and a new exposure is initiated immediately. This mode allows the fastest possible speed. And, because the charge only has to transfer to the adjacent row, there is no smearing.

Non-overlapped mode operation is selected automatically by the controlling software when the exposure time is less than the readout time. In non-overlapped operation, at the end of the exposure time, the image is transferred to the storage sites and no further accumulation occurs (the photo-receptors are switched off). The accumulated charge on

each cell of the array is transferred out of the CCD array, amplified, and sent to the controller as an analog signal, where it is digitized prior to transfer to the computer. .

Note that mechanical shuttering is not required in either mode, although it is available as an option. Mechanical shuttering allows a much higher on/off ratio to be attained, which may offer distinct advantages with short exposure times.

Timing Options in Overlapped Readout Mode

Interline CCD sensors have columns of imaging cells alternating with columns of storage cells. During readout, the charge stored in the photo-sensitive imaging cells move only one row to the adjacent storage cells. From there they move downwards to the readout register and from there to the output node. This scheme serves to allow high speeds, no smearing and shutterless operation, a distinct advantage over frame-transfer sensors where the cell contents can be contaminated by the charge in other cells as data is moved across the CCD and under the mask.

There are two timing options available in the overlapped mode, Free Run and External Sync. Select **None** as the Shutter Type if using WinView/32 software and operating without a shutter. In both Free Run and External Sync operation, the array photosensors see light continuously. The *actual exposure time* is the time between data transfers from a photo-sensitive imaging cell to the adjacent storage cell, and may be longer than the programmed exposure, t_{exp}. Data transfer from the photo-sensitive imaging cells to the storage cells occurs very quickly at the start of each readout. During the read, the stored data is shifted to the array's readout register and from there to the output node.

In Free Run overlapped mode operation, the imaging cells are exposed for the set exposure time (t_{exp}). Then the data transfer to the storage cells takes place, marking the start of the read and the beginning of a new exposure.

In the External Sync mode, *overlapped operation only is provided.* The camera reads out one frame for every External Sync pulse received, providing the frequency of the External Sync pulse does not exceed the maximum rate possible with the system. A sync pulse must be detected before the subsequent readout can occur. If operating without a shutter, the actual exposure time is set by the period of the sync signal. There is one exception as described in the following paragraph.

If the programmed exposure time is less than the readout time in the External Sync mode, then the actual exposure time is simply equal to t_R, the readout time (marked by **NOTSCAN** low). More specifically, if the readout time, t_R, is greater than the sum of t_{w1}, the time the controller waits for the first External Sync pulse, plus t_{exp}, the programmed exposure time, plus t_c, the shutter compensation time (zero with **None** selected as the Shutter type), then the actual exposure time will equal t_R. If an External Sync pulse is detected during each read, frames will follow one another as rapidly as possible as shown in Figure 44. In the figures that follow, *Shutter* indicates the *programmed* exposure time. If a shutter were present and active, it would also be the *actual* exposure time.

Prior to the first readout, clean cycles are performed on the array. When the software issues a Start Acquisition command, the first exposure begins. Time counting of the programmed Exposure Time begins when the sync pulse arrives at the Ext Sync connector. The exposure ends on completion of the programmed Exposure Time. Then the data acquired during the first exposure is read out while the next frame of data is

being acquired. This pattern continues for the duration of the experiment so that, during each frame, the data acquired during the previous frame is read out.
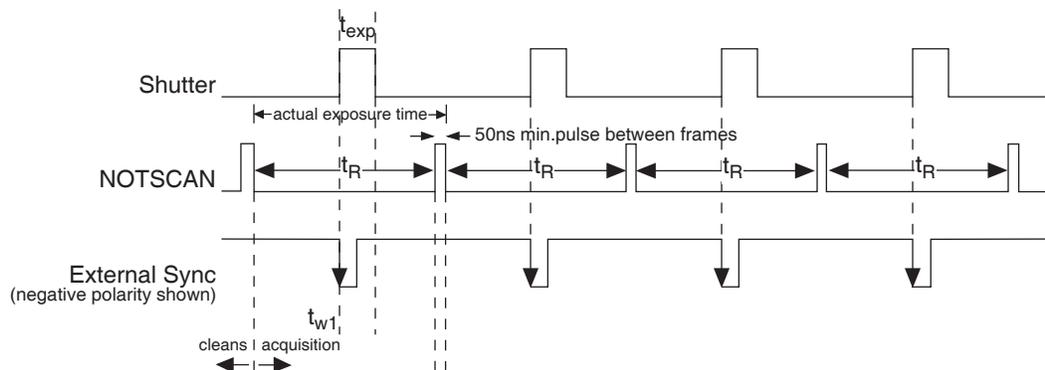

Figure 44. Overlapped Mode where $t_{w1} + t_{exp} + t_c < t_R$

Figure 45 shows the case where the programmed exposure time is greater than the time required to read out the storage half of the array, that is, where $t_{w1} + t_{exp} + t_c > t_R$. In this case, the programmed exposure time will dominate in determining the actual exposure time. In the situation depicted in Figure 45, the External Sync pulse arrives during the readout. As always, the External Sync pulse must be detected before the next readout can occur. However, there is no requirement as to when it must be applied or even that it be periodic. The timing of the External Sync pulse is entirely at the your discretion. In Figure 46, the External Sync pulse is shown arriving after the read. Detection of the External Sync pulse enables a new readout to occur on completion $t_{exp} + t_c$.
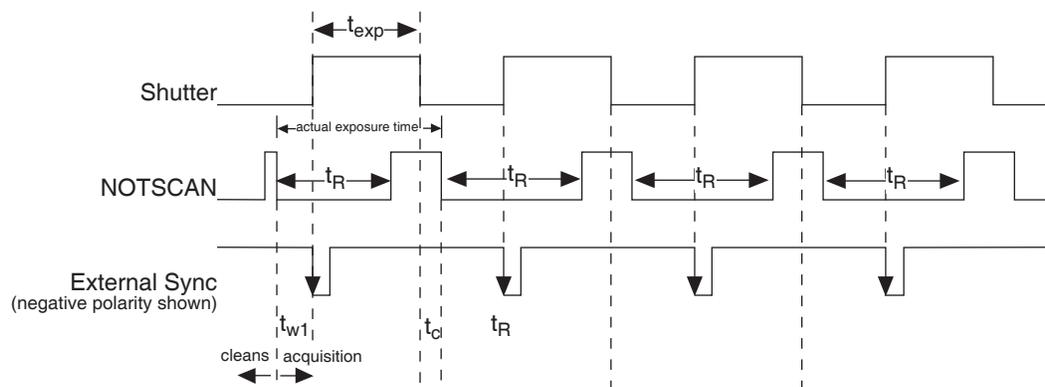
Figure 45. Overlapped Mode where $t_{w1} + t_{exp} + t_c > t_R$
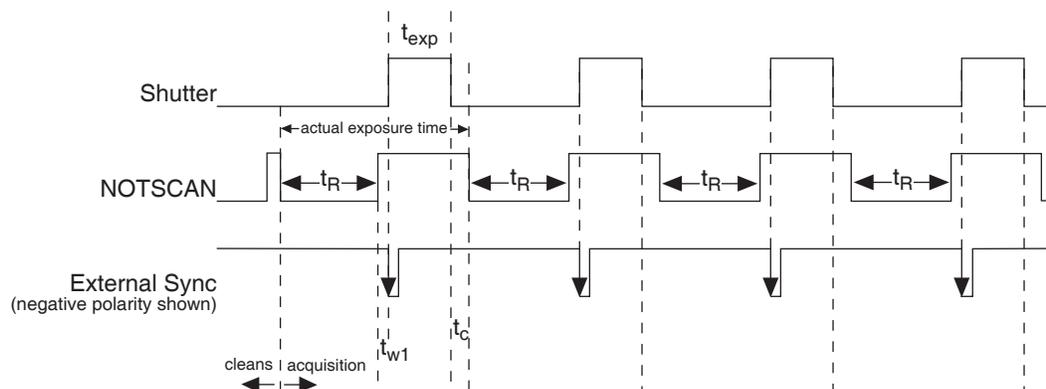
Figure 46. Overlapped Mode where Pulse arrives after Readout

Exposure

CCD arrays perform three essential functions: photons are transduced to electrons, integrated and stored, and finally read out. The software allows you to set the length of time that incoming light will be allowed to integrated on the CCD. This time is called the exposure time. Interline transfer CCDs contain alternate columns of imaging and storage cells that work in pairs. Light impinging on the imaging cells cause a charge buildup. As previously explained, the operating mode is always overlapped unless the exposure time is shorter than the readout time, in which case non-overlapped operation is automatically selected.

Note: The storage cells of an interline chip are quite light insensitive (the ratio of the light sensitivity of the storage cells, which are masked, to the light sensitivity of the imaging cells is ~4000:1). However, even with a rejection ratio of ~4000:1, there may be situations where this may not be sufficient to prevent light leakage from significantly affecting the data. That this is so becomes apparent when the on/off time factors are considered. In an experiment with a very short exposure compared to the readout rate, the ratio of the readout time to the exposure time may easily be of the same order as the rejection ratio of the interline chip storage cells. Where this is the case, the signal buildup in the storage cells during the readout time may equal the signal transferred from the imaging cells to the storage cells at the end of the exposure time. The effect of this signal will be to cause data smearing. The only solutions to this problem at this time are to increase the exposure time to where the effect is insignificant, use a shutter, or to use a gated light source.

Exposure with a Mechanical Shutter

As previously discussed, even though an interline CCD ordinarily doesn't require a mechanical shutter, a mechanical shutter can be incorporated into the system advantageously in certain situations. The diagram in Figure 47 shows how the exposure period is measured in shuttered operation. The $\overline{\text{SCAN}}$ output can be used to monitor the exposure and readout cycle (t_R). This signal is also shown in Figure 47. The value of t_c is shutter type dependent, and will be configured automatically for systems shipped with an internal shutter.
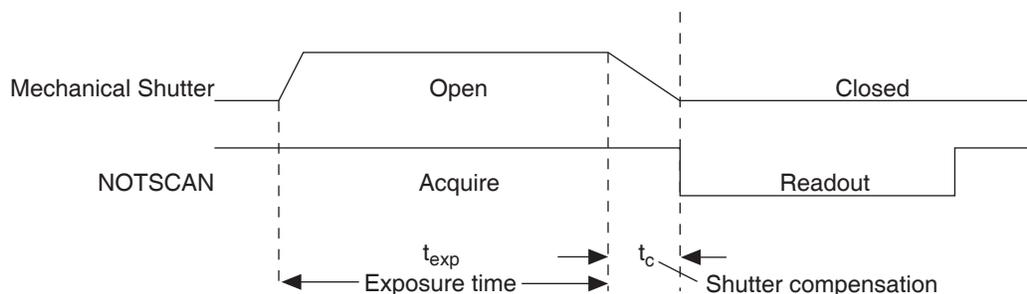
Figure 47. Non-Overlapped Mode Exposure of the CCD with Shutter Compensation

NOTSCAN is low during readout, high during exposure, and high during shutter compensation time.

Since most shutters behave like an iris, the opening and closing of the shutter will cause the center of the CCD to be exposed slightly longer than the edges. It is important to realize this physical limitation, particularly when using short exposures.

Continuous Exposure (no shuttering)

Cameras with interline capability may be used with or without a shutter. When operating without a shutter, image smearing may occur due to a small amount of light leaking through to the storage cells during the readout time. In the case of lens-coupled intensified cameras (ICCDs), this effect can be eliminated by using a fast phosphor and gating the intensifier at the same frame rate as the CCD.

The fraction of total signal due to smearing is the ratio of the readout time to the exposure time divided by ~4000. Faster readout or longer exposure times will minimize this effect. Note that while 1% smear is insignificant in an 8-bit camera (256 gray levels), in a 12-bit camera (over 4,000 gray levels) 1% smearing is over 40 counts, enough to obscure faint features in a high dynamic range image.

Readout of the Array

In this section, a simple 6×4 pixel interline CCD is used to demonstrate how charge is shifted and digitized. As described below, two different types of readout, overlapped and non-overlapped can occur. In overlapped operation, each exposure begins while the readout of the previous one is still in progress. In non-overlapped operation (selected automatically if the exposure time is shorter than the readout time) each readout goes to completion before the next exposure begins.

Overlapped Operation Exposure and Readout

Figure 48 illustrates exposure and readout when operating in the overlapped mode. Figure 48 contains four parts, each depicting a later stage in the exposure-readout cycle. Eight columns of cells are shown. Columns 1, 3, 5 and 7 contain imaging cells while columns 2, 4, 6 and 8 contain storage cells. The readout register is shown below the array.

Part 1 of the figure shows the array early in the exposure. The imaging cells contain charge proportional to the amount of light integrated on each of them. The storage cells are empty because no charge has been transferred to them. The arrows between adjacent imaging and storage cells indicate the direction the charge will be shifted when the transfer occurs.

Part 2 of Figure 48 shows the situation early in the readout. The charge in the imaging cells has been transferred to the adjacent storage cells and downshifting to the readout register has started. Note that a new exposure begins immediately.

Part 3 of Figure 48 shows the transfer to the readout register continuing. The uppermost two cells in each column are shown empty. Each row of charges is moved in turn into the readout register and from there out of the array for further processing. The process continues until all charges have been completely transferred out of the array. The imaging cells continue accumulating charge throughout the readout process. Integrating in this way while the readout takes place achieves the maximum possible time efficiency.

Part 4 of Figure 48 illustrates the situation at the end of the readout. The storage cells and readout register are empty, but charge accumulation in the imaging cells continues until the end of the programmed exposure.

1 Empty Readout Register. Exposure has ended and image is being transferred to storage cells.

A1	B1	C1
A2	B2	C2
A3	B3	C3
A4	B4	C4
A5	B5	C5
A6	B6	C6

2 Image has been shifted to storage cells, first line has been shifted to Readout Register, and second exposure begins.

	A1	B1	C1

A2	D1	B2	E1	C2	F1
A3	D2	B3	E2	C3	F2
A4	D3	B4	E3	C4	F3
A5	D4	B5	E4	C5	F4
A6	D5	B6	E5	C6	F5
	D6		E6		F6

3 Charge from first cell has been shifted to the Output Node.

A1	B1	C1	

A2	D1	B2	E1	C2	F1
A3	D2	B3	E2	C3	F2
A4	D3	B4	E3	C4	F3
A5	D4	B5	E4	C5	F4
A6	D5	B6	E5	C6	F5
	D6		E6		F6

4 After first image is read out, storage cells are empty. Second exposure continues.

	D1		E1		F1
	D2		E2		F2
	D3		E3		F3
	D4		E4		F4
	D5		E5		F5
	D6		E6		F6

Figure 48. Overlapped Mode Exposure and Readout

Non-Overlapped Operation Exposure and Readout

Figure 49 illustrates exposure and readout when operating in the non-overlapped mode. Non-overlapped operation occurs automatically any time the exposure time is shorter than the readout time. Figure 49 contains four parts, each depicting a later stage in the exposure-readout cycle.

Part 1 of the figure shows the array early in the exposure. The imaging cells contain charge proportional to the amount of light integrated on each of them. The storage cells are empty

because no charge has been transferred to them. The arrows between adjacent imaging and storage cells indicate the direction the charge will be shifted when the transfer occurs.

Part 2 of Figure 49 shows the situation early in the readout cycle. The charge in the imaging cells has been transferred to the adjacent storage cells and down-shifting to the readout register has started. Note that a second exposure doesn't begin while the readout is in progress.

Part 3 of Figure 49 shows the transfer to the readout register continuing. Two cells in each column are shown empty, indicating the continuing downward movement of charge. The charges are moved to the readout register and from there out of the array for further processing. The process continues until the storage cells' contents have been completely transferred out of the array. The imaging cells are electronically switched off and do not accumulate any charge as the readout takes place. Because this scheme is less time efficient than that used in the overlapped mode, the frame rate may be lower in non-overlapped operation than it is in overlapped operation with the some exposure time settings.

Part 4 of Figure 49 illustrates the situation at the end of the readout. Both the imaging and storage cells are empty. In Freerun operation, the imaging cells will be switched back on immediately, allowing charge accumulation to begin. In Ext Sync operation with no PreOpen, they are not switched back on until after the External Sync pulse is detected.
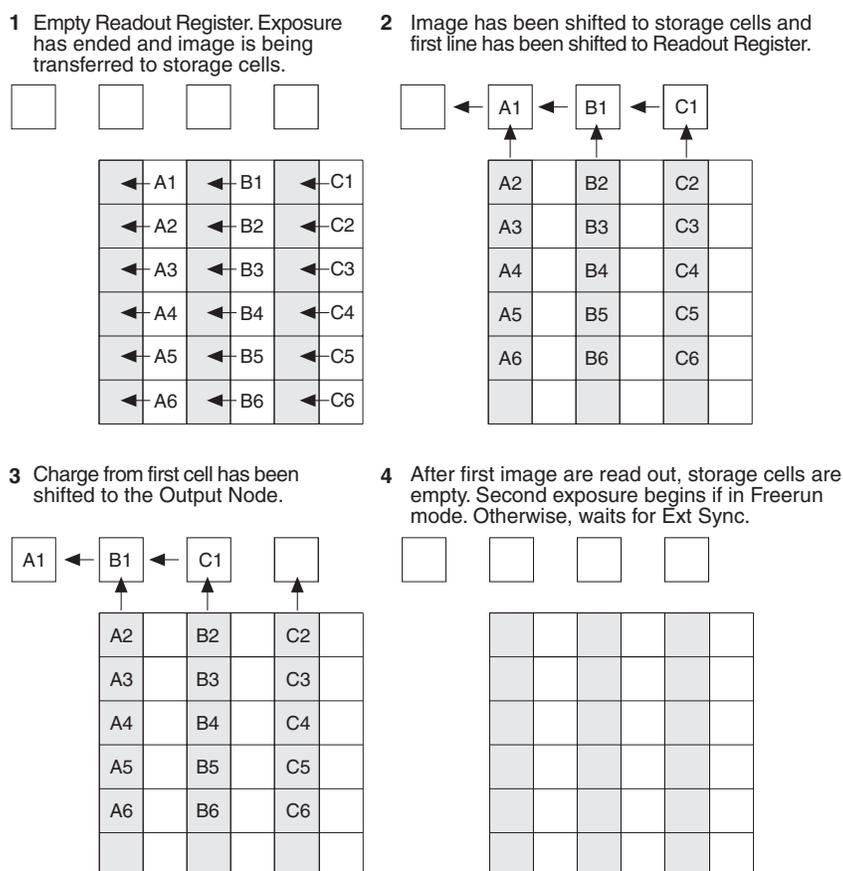
Figure 49. Non-Overlapped Mode Exposure and Readout

A subsection of the CCD can be read out at full resolution, sometimes increasing the readout rate while retaining the highest resolution in the region of interest (ROI).

Image readout with binning

Binning is the process of adding the data from adjacent cells together. It can be accomplished in either hardware or software. Rectangular groups of cells of any size may be binned together, subject to some hardware and software limitations.

Hardware binning is performed *before* the signal is read out by the preamplifier. For signal levels that are readout noise limited this method improves S/N ratio linearly with the number of cells grouped together. For signals large enough to render the camera photon shot noise limited, the S/N ratio improvement is roughly proportional to the square-root of the number of pixels binned.

Figure 50 shows an example of 2×2 binning. Each cell of the image displayed by the software represents 4 cells of the CCD array. Rectangular bins of any size are possible.
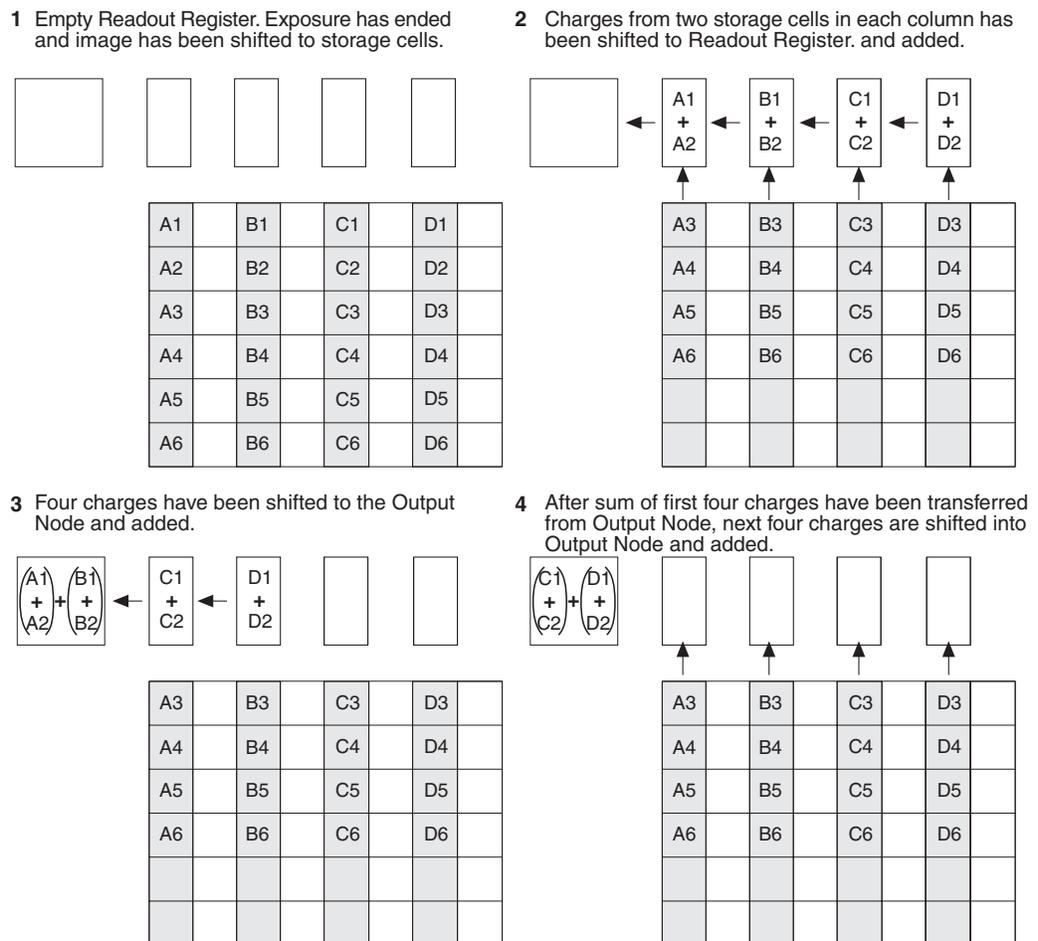
Figure 50. 2×2 Binning for Images

DIF Camera
(Double Image Feature)

Introduction

This Appendix describes operation of a DIF system. Both the Controller and a Interline camera must have factory modifications installed for DIF operation. In addition to the internal changes and installation of a back panel switch, a camera modified for DIF operation would ordinarily include a mechanical shutter. Execution of the DIF functions is done via the WinView/32 software (v2.2 or higher), which, when controlling a DIF system, provides three timing modes unique to DIF systems.

Basically, a DIF system is one that has been factory modified to allow images to be taken in pairs with very short exposure times (as small as 1 µs). This capability makes it ideal for use in experiments where the goal is to obtain two fast successive images for the purpose of characterizing a time-differentiated laser-strobed process. LIF and velocity measurements are specific measurements that can be easily performed using the DIF system.

The ability of the interline chip to quickly transfer an image under the masked columns and hold it there makes this method of acquiring images possible. As soon as the first image is acquired, it is shifted under the masked area and held. The second exposure begins and is continuously held in the photodiode region until the mechanical shutter closes. Light entering the camera while waiting for the shutter to close is small compared to that captured during the strobed event and has little effect on the acquired data.

In addition to the FreeRun mode, which allows single image acquisitions, three DIF timing modes, IEC (Internal Exposure Control), EEC (External Exposure Control) and ESABI (Electronic Shutter Active Between Images) are provided. Each works basically as follows.

IEC: Allows two *successive* fast images *of equal duration* to be acquired, with the second image acquisition taking place immediately after the first. Acquisition is initiated by applying a single externally derived trigger to the controllers **Ext. Sync** connector.

EEC: Allows two *successive* fast images *of differing duration* to be acquired, with the second image acquisition taking place immediately after the first. Acquisition is initiated by applying a single externally derived trigger to the controllers **Ext. Sync** connector, the same as in IEC operation.

ESABI: Allows two fast images *of equal duration* to be acquired. Unlike the IEC and EEC modes, in the ESABI mode, two pulses are applied to the Ext. Sync connector. Each initiates a separate acquisition, allowing the you to set the time between acquisitions by externally adjusting the time between the two applied pulses.

When the data is saved, both images are saved in a single *.spe file. The header is followed by frame 1 and then immediately afterwards by frame 2. This system makes it convenient to later load the images from the file for post processing analysis.

Notes:

1. For most of the MicroMAX DIF cameras, the **ESABI** timing mode is activated and deactivated via the application software. If a MicroMAX DIF camera has a switch on its back panel, this switch must be set to the **ACTIVE** position for operation in the **ESABI** timing mode. At all other times it must be set to **INACTIVE**.

2. The Readout Mode set on the Controller/Camera Hardware Setup tab page *must* be set to **Full Frame** for DIF operation. Do *not* select the **Interline** Readout mode, even though, intuitively, **Interline** may seem to be the logical choice.

3. In the IEC, EEC or ESABI timing mode, set the **Number of Images** to 2 and **Accumulations** to 1.

4. On the Setup Hardware **Cleans/Skips** tab page, click the **Load Factory Values** button. This step is necessary for proper operation of the interline camera.

Timing Modes

The timing modes on the **Timing** tab page (Acquisition menu - Experiment Setup) when using a DIF camera area as follows:

> **FREERUN** (single shot),
> **IEC:** Internal Exposure Control (two shot),
> **EEC:** External Exposure Control (two shot), and
> **ESABI:** Electronic Shutter Active Between Images (two shot).

Each of these modes is discussed in the following paragraphs.

Free Run

The Free Run mode allows the user to capture single images. The exposure time is set on the Experiment Setup **Main** tab page, the same as in non-DIF systems, with the difference that the exposure time can be as short as one 1 µs (maximum exposure time is 14.3 minutes). It often proves convenient to simply disable the mechanical shutter open in Free Run operation. The shutter requires ~8 ms to open and 8 ms to close. The camera waits until the shutter is completely open before acquiring the image, and in a typical experiment, the second image acquisition will be over long before the shutter closes. Readout doesn't occur until the shutter closes.

The $\overline{\text{READY}}$ signal output of the controller can be used to trigger external equipment, such as the laser. As soon as the shutter is completely opened and all of the cleans have been performed, $\overline{\text{READY}}$ goes low to indicate that the camera is ready to capture an image. As soon as the first exposure actually begins, $\overline{\text{READY}}$ returns high, as shown in Figure 51. Thus, the positive going edge of the $\overline{\text{READY}}$ output marks the start of the first exposure. In Freerun operation, the time that $\overline{\text{READY}}$ remains low will typically be in the range of 400 to 600 ns.

$\overline{\text{READY}}$

400 ns ⟶

EXPOSURE
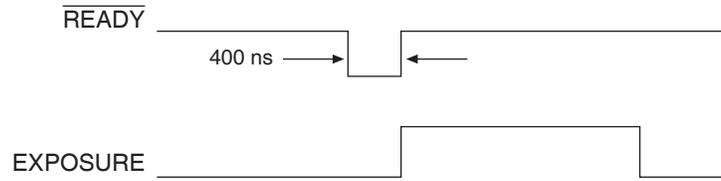
Figure 51. Freerun Mode Timing

Example: Figure 52 shows an experiment where the rising edge of the $\overline{\textbf{READY}}$ signal is used to trigger a DG535 Delay Generator, which provides the required delay and triggers a laser source, Q switch, or other device.

| Computer | Controller | $\overline{\text{READY}}$ | DG535 |

| Camera Head | | | Q Switch |
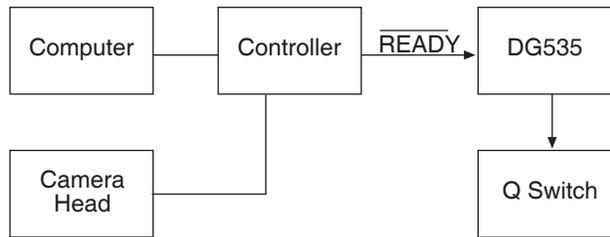
Figure 52. Setup using $\overline{\textbf{READY}}$ to trigger an Event

Figure 53 illustrates the timing for a typical experiment like that shown in Figure 52.

$\overline{\text{READY}}$

400 ns ⟶

EXPOSURE

To Q Switch

←1 µs→

←⟶ 2 µs ⟶
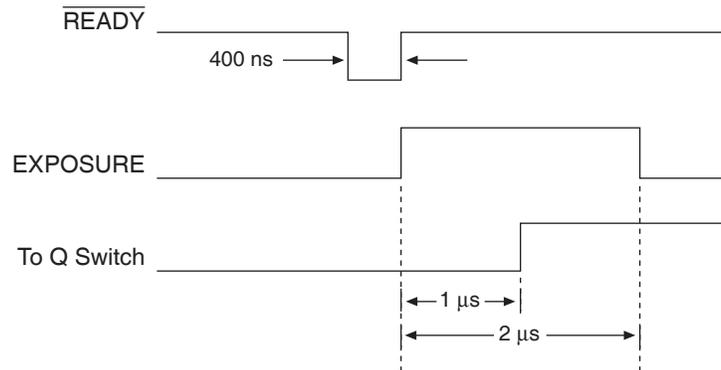
Figure 53. Timing for Experiment Setup shown in Figure 52

Summary of Free Run Timing mode

- Allows user to capture single images.

- Requires that the switch, if present on the back of the camera, be set to **INACTIVE**.

- Uses Exposure Time set via software Experiment Setup.

- Exposure time range is 1 µs < Exp. Time < 14.3 minutes

- Exposure does not occur until the mechanical shutter is completely open and readout does not begin until the mechanical shutter is completely closed.

- The mechanical shutter may, however, be disabled open.

- The $\overline{\text{READY}}$ signal on the back of the controller may be used as a trigger to other external hardware. $\overline{\text{READY}}$ goes low when the system is ready to capture an image, then is reset high once exposure begins. In the **FREERUN** timing mode, this will be a short (400 ns to 600 ns) TTL 0 pulse.

IEC (Internal Exposure Control)

In this mode, a single external trigger applied to **Ext Sync** initiates two successive image acquisitions of equal duration. The Exposure Time is set in software (Experiment Setup **Main** tab page and elsewhere) the same as in a standard system and can be as short as 1 µs. On initiating the acquisition (**ACQ** button or **Acquire** on the Acquisition menu), the initialization routine runs and the shutter opens. When the shutter is completely open, $\overline{\text{READY}}$ drops low and remains in that state until an external trigger is applied to **Ext Sync**. Continuous cleaning takes place until the trigger is applied. When the trigger is sensed, the first exposure begins and the first image is captured (shifted under the masked columns and held there). The exposure for capture of the second image begins. This sequence is illustrated in Figure 54.

If an external trigger is applied before $\overline{\text{READY}}$ goes low, it will be ignored. Thus the trigger source could be running continuously at some repetition rate (as long as that rep rate is fairly slow), but capture wouldn't occur until $\overline{\text{READY}}$ goes low. Once that trigger comes in, it begins exposure of the first image. The exposure time is that set on the Experiment Setup **Main** tab page. For example, if the exposure time is set to 5 µs, the first image will be 5 µs. After an additional 5 µs (second exposure), the shutter will begin to close. Even though the shutter takes ~8 ms to close, the presumption is that the strobe will be timed to occur during the 5 µs second exposure time. It would also be possible to strobe and capture while the shutter is in the act of closing. However, that would generally not be advisable because it would introduce non-linearity effects from the closing shutter. It is better to have capture occur during the time allotted for it. Once the shutter is closed, the readout begins. The first image captured is the first one read out.

Example 1: An external trigger initiates the imaging process. $\overline{\text{READY}}$ goes low when the system is ready. Once $\overline{\text{READY}}$ is low, an external trigger applied to **Ext Sync** initiates the double image capture. Figure 54 illustrates the timing for a typical IEC experiment with an exposure time of 5 µs.
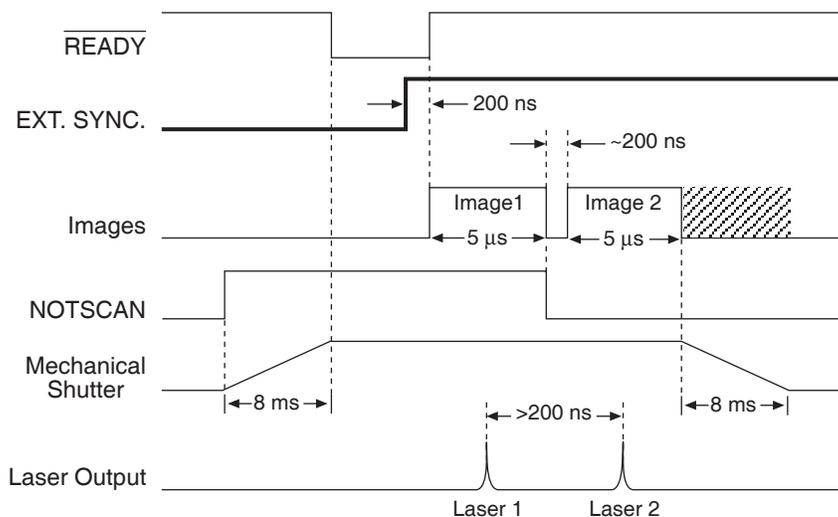
Figure 54. Timing Diagram for Typical IEC Measurement

Figure 55 illustrates the interconnections that might be used for such an experiment with two lasers. Figure 56 shows the timing for the two-laser experiment.
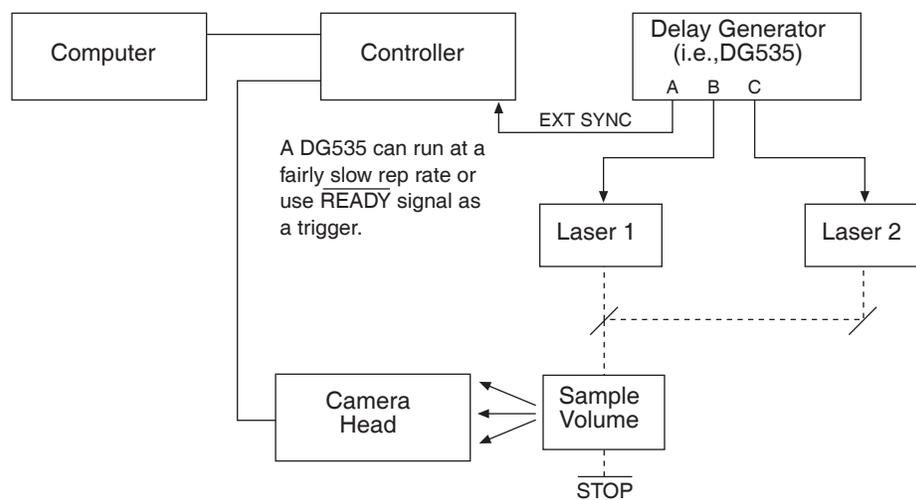
Figure 55. Setup for IEC Eexperiment with Two Lasers
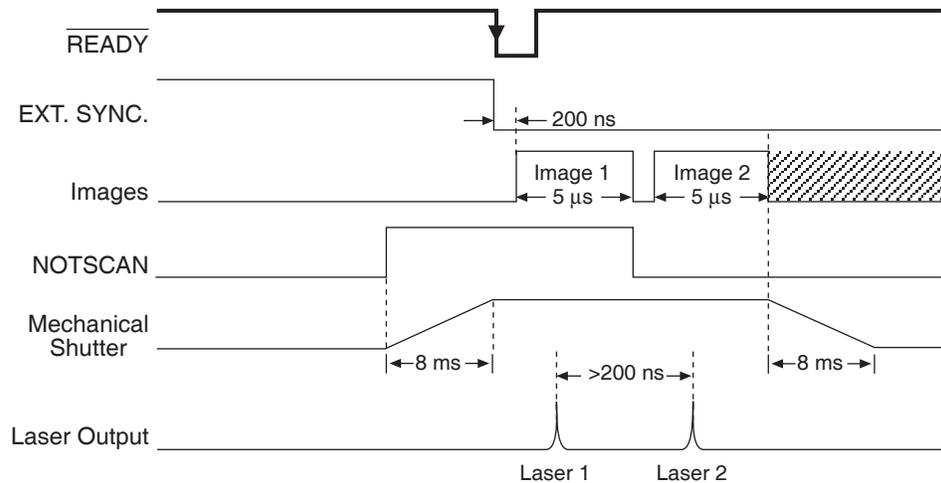
Figure 56. Timing Diagram for IEC Experiment with Two Lasers

Example 2: As shown in Figure 57, the $\overline{\text{READY}}$ signal from the controller can be used to trigger the controller by connecting it back into the **EXT SYNC** connector. At the same time, it can be used to trigger a DG535.
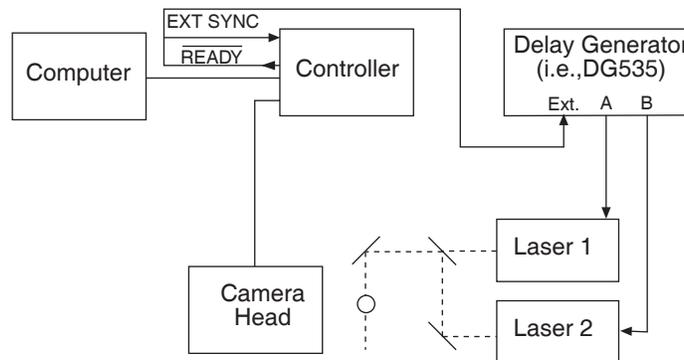
Figure 57. Another Hardware Setup for an IEC Measurement

Note: This setup will *not* work in the **EEC** mode or the **ESABI** mode.

Summary of IEC Timing mode

•   Gives the user the ability to capture two images before readout.

•   Requires that the switch, if present on the back of the camera, be set to **INACTIVE**.

•   The Exposure Time set in software on the Experiment Setup **Main** tab page becomes the exposure time of the first image and also the wait before closing the mechanical shutter.

•   An external trigger is required to initiate the imaging process. The $\overline{\text{READY}}$ goes low when the system is ready. Once $\overline{\text{READY}}$ is low, an external trigger applied to the **EXT SYNC** connector initiates the double image capture.

EEC (External Exposure Control)

Gives the user the ability to capture two images before readout with a different exposure time for each. EEC uses the external trigger to control the exposure time of the first image and the exposure time set in software to control the exposure time of the second image. When the external trigger applied to **Ext Sync** is detected, the first exposure begins. The end of the trigger marks the end of the first image and the start of the second. After an interval equal to the exposure time set on the Experiment Setup **Main** tab page, the shutter closes. As in the IEC mode, the system is receptive to an applied trigger when $\overline{\text{READY}}$ goes low. Note that the shutter can be disabled open. With the shutter disabled open, if reading out a full array, the second exposure time would actually last ~1.4 s. If reading out a single strip, the readout time (and hence the second exposure) would be much shorter, on the order of a few hundred microseconds. Generally though, the experiment timing would be set up so that the second strobed event would occur during the second image time as set by the Exposure Time parameter on the Experiment Setup **Main** tab page.

Example: The exposure time for the first image is controlled with the signal applied to the **EXT. SYNC** connector. The exposure time for the second image is the exposure time set in software under Experiment Setup. An external trigger supplied by the user is required to initiate the imaging process and control the first image exposure time. The controller $\overline{\text{READY}}$ signal goes low when the camera is ready to begin imaging. Figure 58 illustrates an EEC timing example.
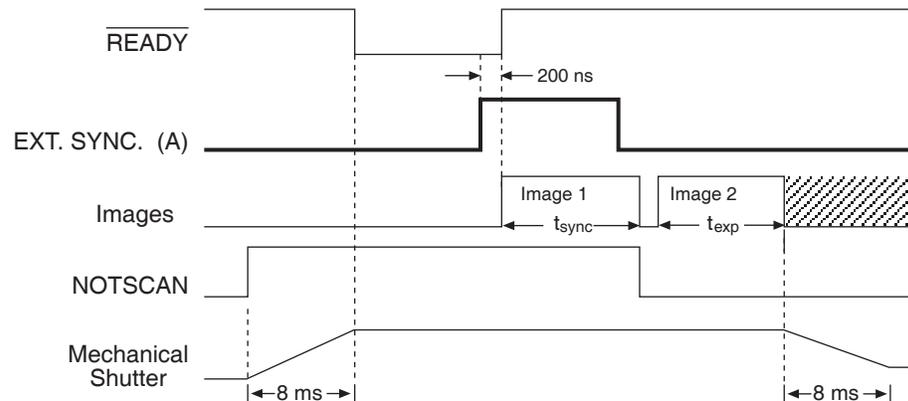
Figure 58. EEC Timing Example with Exposure Time in Software set to t_{ex}

Summary of EEC Timing mode

- Enables double image capture under external control.

- Requires that the switch, if present on the back of the camera, be set to **INACTIVE**.

- The width of the pulse applied to **Ext Sync** sets the exposure time of the first image. The Exposure Time set in software on the Experiment Setup **Main** tab page sets the second image time, at the end of which the shutter begins to close.

- An external trigger is required to initiate the imaging process. The $\overline{\text{READY}}$ goes low when the system is ready. Once $\overline{\text{READY}}$ is low, an external trigger applied to the **Ext Sync** connector initiates the double image capture.

ESABI (Electronic Shutter Active Between Images)

The last timing mode, ESABI, allows separation time between the two images. This mode gives the user the ability to capture two images and use the interline chip's electronic shutter feature between images so that no signal is integrated in the time between. The exposure time for both images is the same but they can be separated in time. Each time the camera is ready to receive a trigger, $\overline{\text{READY}}$ goes low. Thus $\overline{\text{READY}}$ goes low twice during each ESABI cycle and the controller can be triggered once by a sync pulse applied to **Ext Sync** each time. Thus two sync pulses are required, one for each image, during each double capture. The programmed Exposure Time, as set on the Experiment Setup **Main** tab page, sets the first image time and the time after the start of the second image time when the shutter begins to close. Figure 59 illustrates ESABI mode timing.

Note that charge produced by light impinging on the photosensors during the interval between the two images is discarded and does not affect the second image. The time between the first and second image can be as long as required according to the experimental requirements. This can be particularly useful in fluorescence measurements. By doing captures with different intervals between the two images, the fluorescence decay characteristics can be easily measured.
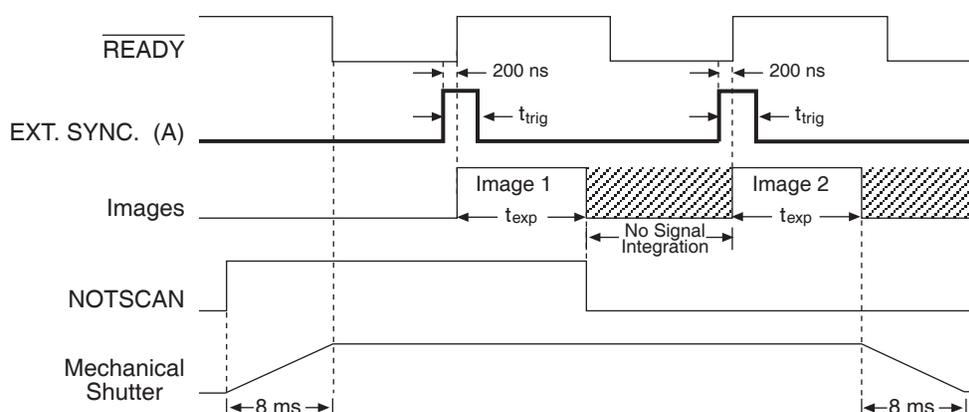
Figure 59. ESABI Timing Example; Image Exposure Time = t_{exp} set in Software

Note: To prevent the second image from occurring immediately after the first one, the input trigger pulse, t_{trig}, must be shorter than the exposure time t_{exp}.

Summary of ESABI Timing mode

- The exposure time selected in Experiment Setup sets the exposure time of both the first and second image.

- Requires that the switch, if present on the back of the camera, be set to **INACTIVE**.

- An externally derived trigger edge applied to **Ext Sync** is required to begin each image exposure period.

- $\overline{\text{READY}}$ goes low when the system is ready to capture *each* image.

Tips and Tricks

Lab Illumination

In DIF measurements, it is necessary to remain mindful of the possibility of laboratory light affecting the images. Because the first image can be timed with precision, laboratory light that reaches the camera would generally not be a problem in the first image, particularly if the capture time is short (few microseconds). The second image, on the other hand, is much more susceptible to degradation from laboratory illumination because, even though the second image time may be set to just a few microseconds, the time to close the shutter, ~8 ms, must be added to that value. Light impinging on the photosensors during that time will be integrated with the second image. Unless the experiment is arranged so that background light can't reach the camera, or unless the signal is quite bright, the possibility of the second image becoming degraded must be considered. Where this source of degradation is a problem, the solution may be to sharply reduce the laboratory illumination. It should be noted though, that the signal from many strobed measurements will be sufficiently bright to allow normal laboratory illumination to be maintained.

Background Subtraction

In any of the double imaging modes, a good idea would be to block both of your light sources and go ahead and take two images in the same DIF mode and with the same settings as will be used for the real measurements. The result will be two background images that can later be subtracted from the experimental data images.

Background subtraction allows you to automatically subtract any constant background in your signal. This includes both constant offsets caused by the amplifier system in the controller as well as time-dependent (but constant for a fixed integration time) buildup of dark charge. The background subtract equation is:

$$(\text{Raw image data} - \text{Background}) = \text{Corrected image data}.$$

When background and flatfield operations are both performed, background subtraction is always performed first.

Flatfield Correction

Flatfield correction allows the user to divide out small nonuniformities in gain from pixel to pixel. Flatfield correction is done before the images are saved to RAM or disk. Directions for doing Flatfield correction are provided in the WinView/32 software manual.

Mask Bleed-through Correction

As described previously, the first image is stored under the mask while the second image is being acquired. Although the mask is basically opaque (light attenuation is on the order of 4000:1), a small amount of illumination does get through and could influence some measurements. One solution would be to establish a correction file by taking the first image with the light source dark, and the second image with the light source on. Any bleed through the mask during the second image will appear in the first image. This data could then be stored and used later to correct "real" first images in a post-processing math operation.

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Appendix I

Installing the Computer-Controller Interface

Introduction

This appendix will lead you through the process of installing the communications interface between the ST-133 and the host computer. Following these steps explicitly will help insure proper connection to your computer.

Note: If the computer is purchased from Roper Scientific, it will be shipped with the appropriate card already installed. The USB 2.0 interface is supported by WinView/32 and WinSpec/32, version 2.5.14 and higher. The ISA interface is supported in WinView/32 and WinSpec/32 through version 2.5.X. ISA will not be supported by versions 2.6 and higher.

WARNING

To avoid risk of dangerous electrical shock, the computer power should be OFF when installing the computer interface. Users are advised to review the documentation for their computer before performing the installation.

Installing the Application Software

Installation is performed via the WinView/32 or WinSpec/32 installation process. If you are installing WinView or WinSpec for the first time and have a TAXI interface, you should run the installation before the PCI interface card is installed in the host computer. On the **Select Components** dialog box (see Figure 60), click on the **AUTO PCI** button to install the interface card drivers (PCI and the Roper Scientific USB drivers) and the most commonly installed program files. Select the **Custom** button if you want to choose among the available program files or do not want to install the PCI driver.
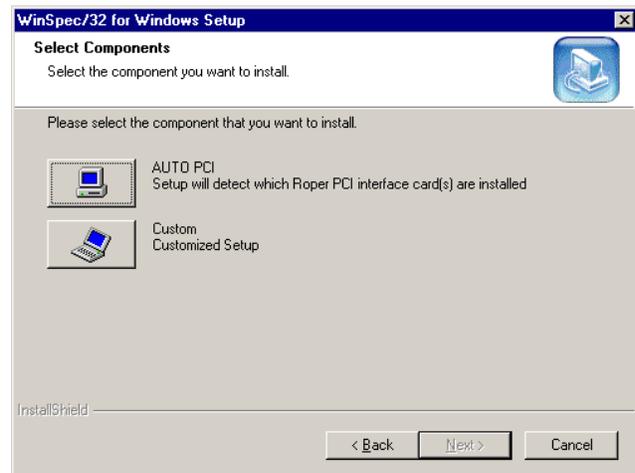
Figure 60. WinSpec Installation: Interface Card Driver Selection

Note: WinView/32 and WinSpec/32 (versions 2.6.0 and higher) do not support the ISA interface.

Setting up a PCI Interface

Introduction

A PCI card must be installed in the host computer if the communication between computer and controller uses the TAXI protocol (i.e., the **Interface Control Module** installed in the ST-133 has a 9-pin **SERIAL COM** connector as shown in the figure at right). With TAXI protocol, the standard cable provided with an ST-133 is 7.6 meters (25 feet) (cable lengths up to 50 meters are available) and the digitization rate may be as high as 5 MHz.

A computer purchased from Roper Scientific will be shipped with the PCI card already installed. Otherwise, a PCI card will be shipped with the system and you will have to install it in the host computer at your location.

Note: The PCI card can be installed and operated in any Macintosh having a PCI bus, allowing the ST-133 to be controlled from the Macintosh via IPLab™ software and the PI Extension.

Caution

If using WinView/32 or WinSpec/32 software, either **High Speed PCI** or **PCI(Timer)** can be the selected Interface type. This selection is accessed on the **Hardware Setup|Interface** tab page. **High Speed PCI** allows data transfer to be interrupt-driven and gives the highest performance in some situations. **PCI(Timer)** allows data transfer to be controlled by a polling timer. This selection is recommended when there are multiple devices sharing the same interrupt.

PCI Installation

To Replace a USB 2.0 Interface Control Module with a TAXI Module: If you ordered a TAXI Interface Control module separately and are retrofitting an ST-133 that you already own, follow the module replacement instructions in *"Removing/Installing a Plug-In Module"* starting on page 83.

To Install a PCI Serial Buffer Card in the Host Computer:

1. Review the documentation for your computer and PCI card before continuing with this installation.

2. To avoid risk of dangerous electrical shock and damage to the computer, verify that the computer power is OFF.

3. Remove the computer cover and verify that there is an available PCI slot.

4. Install the PCI card in the slot.

5. Make sure that the card is firmly seated and secure it.

6. Replace and secure the computer cover and turn on the computer only. If an error occurs at bootup, either the PCI card was not installed properly or there is an address or interrupt conflict. Refer to *"Power-On Checks", page 105,* for instructions.

Note: The PCI card has no user-changeable jumpers or switches.

Administrator privileges are required under Windows NT®, Windows® 2000, and Windows® XP to install software and hardware.

To Install the PCI Card Driver

The following information assumes that you have already installed the WinView/32 or WinSpec/32 software.

1. After you have secured the PCI card in the computer and replaced the cover, turn the computer on.

2. At bootup, Windows will try to install the new hardware. If it cannot locate the driver, you will be prompted to enter the directory path, either by keyboard entry or by using the browse function.

    If you selected **AUTO PCI** during the application software installation, WinView/32 or WinSpec/32 automatically put the required INF file into the Windows/INF directory and put the PCI card driver file in the "Windows"/System32/ Drivers directory. Refer to Table 8 below for the appropriate file names and locations.

Windows Version	PCI INF Filename Located in "Windows"/INF directory*	PCI Device Driver Name Located in "Windows"/System32/Drivers directory
Windows® 2000 and XP	rspi.inf (in WINNT/INF, for example)	rspipci.sys (in WINNT/System32/Drivers, for example)
Windows NT®	N/A	pi_pci.sys
Windows® 95, 98, and Windows® ME	pii.inf	pivxdpci.vxd

* The INF directory may be hidden.

Table 8. PCI Driver Files and Locations

Power-On Checks
Introduction
Before proceeding, be sure the PCI Serial Buffer Board is firmly mounted in the slot. Replace the cover of the computer and turn on the computer only.

Conflicts
One of the many advantages that PCI offers over ISA is that the whole issue of address and interrupt assignments is user transparent and under BIOS control. As a result, users typically do not have to be concerned about jumpers or switches when installing a PCI card. Nothing more should be required than to plug in the card, make the connections, and operate the system. As it turns out, however, in certain situations conflicts may nevertheless occur and user intervention will be required to resolve them.

Typical PCI motherboards have both ISA and PCI slots and will have both PCI and ISA cards installed. In the case of the ISA cards, the I/O address and Interrupt assignments will have been made by the user and the BIOS will not know which addresses and interrupts have been user assigned. When a PCI card is installed, the BIOS checks for available addresses and interrupt levels and automatically assigns them so that there are no *PCI* address or interrupt conflicts. However, because the BIOS doesn't know about the user-assigned ISA I/O address and interrupt level assignments, it is possible that a PCI card will be assigned an address or interrupt that is already assigned to an ISA card. If this happens, improper operation will result. Specifically, the problems could range from erratic operation under specific conditions to complete system failure. If such a conflict occurs, because the user has no control over the PCI address and interrupt assignments, there will be no recourse but to examine the ISA assignments and change them to values that do not conflict. Most (but by no means all) ISA cards make provision for selecting

alternative I/O addresses and interrupt levels so that conflicts can be resolved. Software is available to help identify specific conflicts.

The following example may serve to illustrate the problem. Suppose you had a system with an ISA network card, a PCI video card and an ISA sound card. Further suppose that you were then going to install a PCI Serial Buffer card. Before installing the PCI Serial card, the I/O address and interrupt assignments for the installed cards might be as follows.

Slot Type	Status	I/O Address(s)	Interrupt
1 (ISA)	ISA Network Card	200-210	11
2 (PCI)	PCI Video Card	FF00-FFFF	15
3 (ISA)	ISA Sound Card	300-304	9
4 (PCI)	Empty	N/A	N/A

Table 9. I/O Address & Interrupt Assignments
Before Installing Serial Card

As shown, there are no conflicts, allowing the three peripheral cards to operate properly. If the PCI Serial card were then installed, the BIOS would interrogate the PCI cards and may reassign them new address and interrupt values as follows.

Slot Type	Status	I/O Address(s)	Interrupt
1 (ISA)	ISA Network Card	200-210	11
2 (PCI)	PCI Video Card	FE00-FEFF	11
3 (ISA)	ISA Sound Card	300-304	9
4 (PCI)	Princeton Instruments PCI Serial Card	FF80-FFFF	15

Table 10. I/O Address & Interrupt Assignments
After Installing Serial Card

As indicated, there is now an interrupt conflict between the ISA Network Card and the PCI Video card (both cards have been assigned Interrupt 11), causing the computer to no longer function normally. This doesn't mean that the PCI Serial card is defective because the computer stops functioning properly when the Serial card is installed. What it does mean is that there is an interrupt conflict that can be resolved by changing the interrupt level on the conflicting Network card in this example. It is up to the user to consult the documentation for any ISA cards to determine how to make the necessary change.

Note: Changing the order of the PCI cards, that is, plugging them into different slots, could change the address and interrupt assignments and possibly resolve the conflict. However, this would be a trial and error process with no guarantee of success.

Diagnostics Software
Many diagnostics programs, both shareware and commercial, are available to help resolve conflicts. Most often, all that's required is a program that will read and report the address and

interrupt assignments for each PCI device in the computer. One such program available from Roper Scientific's Technical Support department is called PCICHECK. When the program is run, it reports the address and interrupt assignments for the first PCI device it finds. Each time the spacebar is pressed, it moves on to the next one and reports the address and interrupt assignments for that one as well. In a few moments this information can be obtained for every PCI device in the computer. Note that, even though there are generally only three PCI slots, the number of PCI devices reported may be larger because some PCI devices may be built onto the motherboard. A good strategy for using the program would be to run it before installing the PCI Serial card. Then run it again after installing the card and note any address or interrupt assignments that may have changed. This will allow you to easily focus on the ones that may be in conflict with address or interrupt assignments on ISA cards. It might be noted that there are many programs, such as the MSD program supplied by Microsoft, that are designed to read and report address and interrupt assignments, including those on ISA cards. Many users have had mixed results at best using these programs.

Operation

There are no operating considerations that are unique to the PCI Serial card. The card can easily accept data as fast as any Princeton Instruments System now available can send it. The incoming data is temporarily stored in the card's memory, and then transferred to the main computer memory when the card gains access to the bus. The PCI bus arbitration scheme assures that, as long as every PCI card conforms to the PCI guidelines, the on-board memory will never overflow.

Unfortunately, there are some PCI peripheral cards that do *not* fully conform to the PCI guidelines and that take control of the bus for longer periods than the PCI specification allows. Certain video cards (particularly those that use the S3 video chip) are notorious in this respect. Usually you will be able to recognize when memory overflow occurs because the displayed video will assume a split-screen appearance and/or the message **Hardware Conflict** will be displayed (WinView/32 or WinSpec/32). At the same time, the LED on the upper edge of the PCI Serial card will light.

Users are thus advised not to take any actions that would worsen the possibility of memory overflow occurring when taking data. In that regard, avoid multitasking while taking data. Specific operations to avoid include multitasking (pressing ALT TAB or ALT ESC to start another program), or running a screensaver program.

Setting up a USB 2.0 Interface

Introduction

Administrator privileges are required under Windows® 2000 and Windows® XP to install software and hardware.

Your system has been configured to use the USB communication protocol if the **Interface Control Module** installed in the ST-133 has a **USB 2.0** connector as shown in the figure at right). The advantages to the USB 2.0 interface are that it uses a much higher data transfer rate than many common serial data formats (such as the TAXI protocol) and it simplifies the connection to external devices. USB supports "plug and play" -- you do not need to be heavily involved in the setup process. The limitations are that the maximum cable length is 5 meters (16.4 feet) and that 1 MHz is currently the upper digitization rate limit for the ST-133.

The USB 2.0 interface is supported by WinView/32 and WinSpec/32, versions 2.5.14 and higher.

USB 2.0 Installation
To Replace a TAXI Module Interface Control Module with a USB 2.0 Module:
If you ordered a USB 2.0 Interface module separately and are retrofitting an ST-133 that you already own, follow the module replacement instructions in *"Removing/Installing a Plug-In Module"* starting on page 83.

To Install the USB 2.0 Interface:

The following information assumes that:
- You have verified that the host computer meets the required specifications for USB 2.0 communication with the camera system (see page 13).
- A USB 2.0 board and its driver are installed in the host computer.
- The ST-133 has an installed USB 2.0 Interface Control module.
- You have already installed the WinView/32 or WinSpec/32 software (versions 2.5.14 and higher). Versions 2.5.14 and higher automatically install the driver and INF files required to support the USB 2.0 Interface Control module.

1. Before installing the Roper Scientific USB2 Interface, we recommend that you defragment the host computer's hard disk. This operation reduces the time the computer spends locating files. Typically, the "defrag" utility "Disk Defragmenter" can be accessed from the Windows® Start menu and can usually accessed from the Programs/Accessories/System Tools subdirectory.

2. After defragmenting the hard disk, turn off the computer and make the USB cable connections between the host computer and the ST-133. Then, turn the ST-133 on before turning on the host computer.

3. At bootup, Windows will detect the Roper Scientific USB2 Interface hardware (i.e., the USB 2.0 Interface Control module). You may be prompted to enter the directory path(s) for the apausbprop.dll and/or the apausb.sys file(s), either by keyboard entry or by using the browse function.

If you selected AUTO PCI during the application software installation, WinView/WinSpec automatically put the required INF, DLL, and USB driver file in the "Windows" directories shown below. Refer to Table 11 below for the appropriate file names and locations.

Windows Version	USB INF Filename Located in "Windows"/INF directory*	USB Properties DLL Located in "Windows"/System32 directory	USB Device Driver Name Located in "Windows"/System32/Drivers directory
Windows® 2000 and XP	rsusb2k.inf (in WINNT/INF, for example)	apausbprop.dll (in WINNT/System32, for example)	apausb.sys (in WINNT/System32/Drivers, for example)

* The INF directory may be hidden.

Table 11. USB Driver Files and Locations

ISA Serial Card

Introduction

ISA Serial boards were available before the PCI board, now standard, or the USB 2.0 interface were developed. ISA Serial Buffer boards are still supported through version 2.5.X of the WinView/32 and WinSpec/32 application software. Version 2.6 and higher will not support ISA.

Note: An ISA serial interface card operated in an ISA slot can support data transfer rates as high as 1 MHz (WinView or WinSpec software ver. 1.4.3 or later).

A screwdriver may be needed to remove screws from the computer (the type varies from computer to computer). A small, flat-bladed screwdriver is needed to connect both ends of the serial cable.

Checking the ISA Serial Board Jumpers

Before installing an ISA Interface Board, its address should be confirmed. The factory default address is 0A00. This address can be confirmed or changed by comparing the 8 dip switches found on the board with Figure 61. The ISA Serial Buffer board is set to interrupt level 10 and uses DMA channels 5 and 6. The interrupt level can be changed by the user, as long as both hardware and software are set to the same interrupt. Figure 61 shows all possible configurations. If the default DMA channels present a problem, contact the factory for more information.

Caution

Since interrupts and DMA channels cannot be shared, make sure no other boards in your computer use this interrupt or these DMA channels.

Installation

1. Remove the expansion slot cover on the rear panel of the I/O slot selected.

2. Insert the ISA Serial Interface card as far as possible into the appropriate ISA socket. Then secure the Serial Buffer Board by reinstalling the expansion slot cover screw.

3. Connect the serial cable to the 9-pin cable on the ISA Serial Buffer Board mounting panel. The other end of the serial cable connects to the SERIAL COM

connector on the TAXI Interface Control Module panel. Take care to tighten the screws at both ends of the cable using a small, flat-bladed screwdriver.
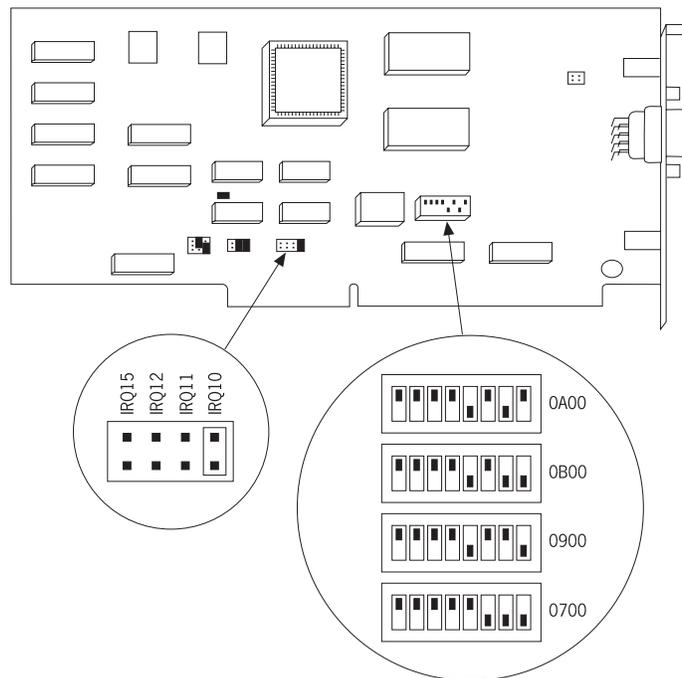
Figure 61. ISA Board Switch and Jumper Settings
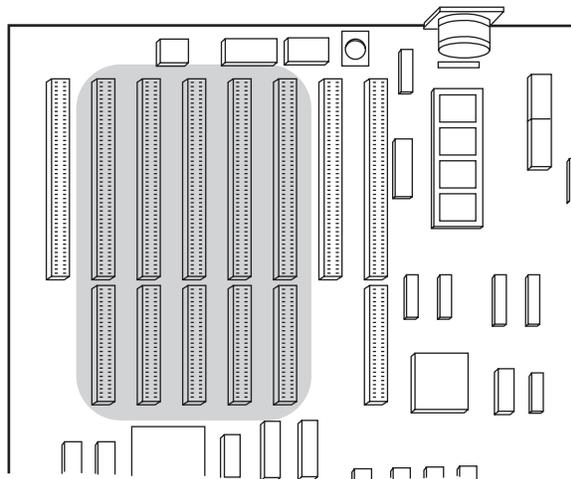
Figure 62. Computer Expansion Slots for installing an ISA Buffer Card

Power-On Checks

Replace the cover of the computer and turn on the computer only. If an error occurs at boot up, either the Serial Buffer Board is not installed properly or there is an address or interrupt conflict. Turn off the computer, try a new address or interrupt and reinstall the card. Be sure the Serial Buffer Board is firmly mounted in the slot.

Warranty & Service

Limited Warranty: Roper Scientific Analytical Instrumentation

Roper Scientific, Inc. ("Roper Scientific," us," "we," "our") makes the following limited warranties. These limited warranties extend to the original purchaser ("You", "you") only and no other purchaser or transferee. We have complete control over all warranties and may alter or terminate any or all warranties at any time we deem necessary.

Basic Limited One (1) Year Warranty

Roper Scientific warrants this product against substantial defects in materials and / or workmanship for a period of up to one (1) year after shipment. During this period, Roper Scientific will repair the product or, at its sole option, repair or replace any defective part without charge to you. You must deliver the entire product to the Roper Scientific factory or, at our option, to a factory-authorized service center. You are responsible for the shipping costs to return the product. International customers should contact their local Roper Scientific authorized representative/distributor for repair information and assistance, or visit our technical support page at www.roperscientific.com.

Limited One (1) Year Warranty on Refurbished or Discontinued Products

Roper Scientific warrants, with the exception of the CCD imaging device (which carries NO WARRANTIES EXPRESS OR IMPLIED), this product against defects in materials or workmanship for a period of up to one (1) year after shipment. During this period, Roper Scientific will repair or replace, at its sole option, any defective parts, without charge to you. You must deliver the entire product to the Roper Scientific factory or, at our option, a factory-authorized service center. You are responsible for the shipping costs to return the product to Roper Scientific. International customers should contact their local Roper Scientific representative/distributor for repair information and assistance or visit our technical support page at www.roperscientific.com.

Normal Wear Item Disclaimer

Roper Scientific does not warrant certain items against defect due to normal wear and tear. These items include internal and external shutters, cables, and connectors. *These items carry no warranty, expressed or implied.*

VersArray (XP) Vacuum Chamber Limited Lifetime Warranty

Roper Scientific warrants that the cooling performance of the system will meet our specifications over the lifetime of the VersArray (XP) detector or Roper Scientific will, at its sole option, repair or replace any vacuum chamber components necessary to restore the cooling performance back to the original specifications at no cost to the original purchaser. *Any failure to "cool to spec" beyond our Basic (1) year limited warranty from date of shipment, due to a non-vacuum-related component failure (e.g., any components that are electrical/electronic) is NOT covered and carries NO WARRANTIES EXPRESSED OR IMPLIED.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Sealed Chamber Integrity Limited 24 Month Warranty

Roper Scientific warrants the sealed chamber integrity of all our products for a period of twenty-four (24) months after shipment. If, at anytime within twenty-four (24) months from the date of delivery, the detector should experience a sealed chamber failure, all parts and labor needed to restore the chamber seal will be covered by us. *Open chamber products carry NO WARRANTY TO THE CCD IMAGING DEVICE, EXPRESSED OR IMPLIED.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Vacuum Integrity Limited 24 Month Warranty

Roper Scientific warrants the vacuum integrity of all our products for a period of up to twenty-four (24) months from the date of shipment. We warrant that the detector head will maintain the factory-set operating temperature without the requirement for customer pumping. Should the detector experience a Vacuum Integrity failure at anytime within twenty-four (24) months from the date of delivery all parts and labor needed to restore the vacuum integrity will be covered by us. Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Image Intensifier Detector Limited One Year Warranty

All image intensifier products are inherently susceptible to Phosphor and/or Photocathode burn (physical damage) when exposed to high intensity light. Roper Scientific warrants, with the exception of image intensifier products that are found to have Phosphor and/or Photocathode burn damage (which carry NO WARRANTIES EXPRESSED OR IMPLIED), all image intensifier products for a period of one (1) year after shipment. *See additional Limited One (1) year Warranty terms and conditions above, which apply to this warranty.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

X-Ray Detector Limited One Year Warranty

Roper Scientific warrants, with the exception of CCD imaging device and fiber optic assembly damage due to X-rays (which carry NO WARRANTIES EXPRESSED OR IMPLIED), all X-ray products for one (1) year after shipment. Se*e additional Basic Limited One (1) year Warranty terms and conditions above, which apply to this warranty.* Responsibility for shipping charges is as described above under our Basic Limited One (1) Year Warranty.

Software Limited Warranty

Roper Scientific warrants all of our manufactured software discs to be free from substantial defects in materials and / or workmanship under normal use for a period of one (1) year from shipment. Roper Scientific does not warrant that the function of the software will meet your requirements or that operation will be uninterrupted or error free. You assume responsibility for selecting the software to achieve your intended results and for the use and results obtained from the software. In addition, during the one (1) year limited warranty. The original purchaser is entitled to receive free version upgrades. Version upgrades supplied free of charge will be in the form of a download from the Internet. Those customers who do not have access to the Internet may obtain the version upgrades on a CD-ROM from our factory for an incidental shipping and handling charge. *See Item 12 in the following section of this warranty ("Your Responsibility") for more information.*

Owner's Manual and Troubleshooting

You should read the owner's manual thoroughly before operating this product. In the unlikely event that you should encounter difficulty operating this product, the owner's manual should be consulted before contacting the Roper Scientific technical support staff or authorized service representative for assistance. If you have consulted the owner's manual and the problem still persists, please contact the Roper Scientific technical support staff or our authorized service representative. *See Item 12 in the following section of this warranty ("Your Responsibility") for more information.*

Your Responsibility

The above Limited Warranties are subject to the following terms and conditions:

1. You must retain your bill of sale (invoice) and present it upon request for service and repairs or provide other proof of purchase satisfactory to Roper Scientific.
2. You must notify the Roper Scientific factory service center within (30) days after you have taken delivery of a product or part that you believe to be defective. With the exception of customers who claim a "technical issue" with the operation of the product or part, all invoices must be paid in full in accordance with the terms of sale. Failure to pay invoices when due may result in the interruption and/or cancellation of your one (1) year limited warranty and/or any other warranty, expressed or implied.
3. All warranty service must be made by the Roper Scientific factory or, at our option, an authorized service center.
4. Before products or parts can be returned for service you must contact the Roper Scientific factory and receive a return authorization number (RMA). Products or parts returned for service without a return authorization evidenced by an RMA will be sent back freight collect.
5. These warranties are effective only if purchased from the Roper Scientific factory or one of our authorized manufacturer's representatives or distributors.
6. Unless specified in the original purchase agreement, Roper Scientific is not responsible for installation, setup, or disassembly at the customer's location.
7. Warranties extend only to defects in materials or workmanship as limited above and do not extend to any product or part which has:
   - been lost or discarded by you;
   - been damaged as a result of misuse, improper installation, faulty or inadequate maintenance or failure to follow instructions furnished by us;
   - had serial numbers removed, altered, defaced, or rendered illegible;
   - been subjected to improper or unauthorized repair; or
   - been damaged due to fire, flood, radiation, or other "acts of God" or other contingencies beyond the control of Roper Scientific.
8. After the warranty period has expired, you may contact the Roper Scientific factory or a Roper Scientific-authorized representative for repair information and/or extended warranty plans.
9. Physically damaged units or units that have been modified are not acceptable for repair in or out of warranty and will be returned as received.

10. All warranties implied by state law or non-U.S. laws, including the implied warranties of merchantability and fitness for a particular purpose, are expressly limited to the duration of the limited warranties set forth above. With the exception of any warranties implied by state law or non-U.S. laws, as hereby limited, the forgoing warranty is exclusive and in lieu of all other warranties, guarantees, agreements, and similar obligations of manufacturer or seller with respect to the repair or replacement of any parts. In no event shall Roper Scientific's liability exceed the cost of the repair or replacement of the defective product or part.

11. This limited warranty gives you specific legal rights and you may also have other rights that may vary from state to state and from country to country. Some states and countries do not allow limitations on how long an implied warranty lasts, when an action may be brought, or the exclusion or limitation of incidental or consequential damages, so the above provisions may not apply to you.

12. When contacting us for technical support or service assistance, please refer to the Roper Scientific factory of purchase, contact your authorized Roper Scientific representative or reseller, or visit our technical support page at www.roperscientific.com.

Contact Information

Roper Scientific's manufacturing facility for this product is located at the following address:

Roper Scientific
3660 Quakerbridge Road
Trenton, NJ 08619 (USA)

Tel: 800-874-9789 / 609-587-9797
Fax: 609-587-1970

Technical Support E-mail: techsupport@roperscientific.com

For technical support and service outside the United States, see our web page at www.roperscientific.com. An up-to-date list of addresses, telephone numbers, and e-mail addresses of Roper Scientific's overseas offices and representatives is maintained on the web page.

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